



*The* FERTILIZER  
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**A**

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## AAS

AAS is short for **atomic absorption spectrometer**.

## Abherent

Any substance that prevents adhesion of a material to itself or to another material is known as abherent. It may be in the form of a dry powder (like talc, mica or diatomaceous earth), a suspension (of say, bentonite) or a soft solid (stearic acid, teflon, waxes, etc.)

Abherents are used as dusting agents and mould washes in the adhesives, rubber and plastic industries. Fats and oils are used as abherents in the baking industry. Fluorocarbon resin coatings on metals are widely used on cooking utensils.

In the fertilizer industry, abherents are used to impart free flowing characteristics to powders like urea, ammonium sulphate, phosphates, etc.

## AB horizon

**Horizons** are soil layers which are roughly parallel to the soil's surface. They are unique in their feel, color, profiles, etc.

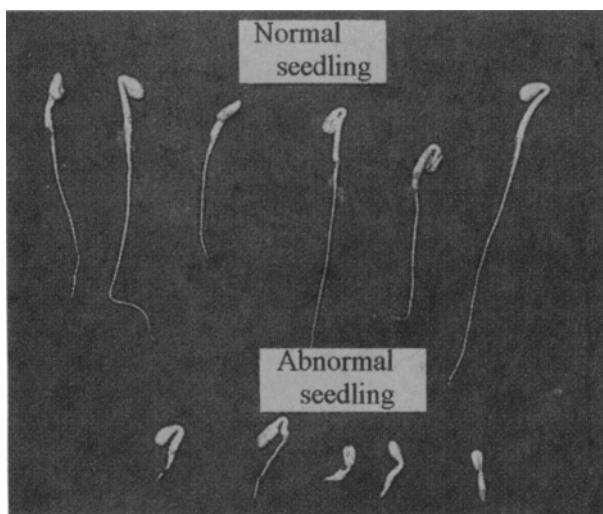
An AB horizon is also called **EB horizon**. It is a transition horizon between the leached E (eluvial) horizon and the accumulation horizon (B.) The AB or EB horizon is more like the A or E above it than like the B below it. (See also Soil horizons.)

## Abiotic factors

Abiotic factors are physical and chemical components of nature, such as rainfall, minerals, heat or wind.

## Abnormal seedlings

Seedlings that do not grow into normal healthy plants even when planted in good quality soils under favorable conditions of light, temperature and water supply are called abnormal seedlings. For example, seedlings with weak or malformed parts, such as stubby roots or split



*Fig. A.1: Normal seedlings show healthy growth, whereas abnormal seedlings show stunted, abnormal growth. (Courtesy: Mahyco Seeds Ltd., Mumbai, India.)*

hypocotyls and those without primary leaves or terminal buds, can be termed abnormal seedlings (Fig. A.1.)

## Abrasion

Gradual erosion of a material, either by physical forces (simultaneous cutting, shearing and tearing) or by chemical degradation (chiefly oxidation) is called abrasion. Abrasion causes the deterioration of materials like fertilizers, textiles, leather, plastics, paints and coatings on solid objects. Temperature is a significant factor in abrasion. Friction raises the temperature of the surface, which in turn, increases the abrasion.

An **abrasive** is a material used for grinding, rubbing, polishing or cleaning a hard surface. Abrasive action can be brought about by the grains on grinding wheels, or by a coating on paper or cloth. Abrasive products, by virtue of their refractory properties and superior hardness, have advantages in speed of operation, smoothness and depth of cut. The products can be used for grinding and polishing (e.g., glass) cutting (e.g., metals), cleaning and machining of metals, and in the manufacture of many products.

Important natural abrasives include diamond, corundum, emery, garnet, feldspar, calcined clay and silica. Silica in its various forms such as sand, sandstone, flint and diatomite is used as an abrasive. Some examples of synthetic abrasives are aluminum oxide, boron carbide, silicon carbide and titanium carbide.

## Abrasion resistance of granule

Abrasion resistance of a granule is its resistance to forming dust, fines and/or being fractured. (See also Granular strength of fertilizers.)

**Abrasive:** See Abrasion

**Abrupt argillic:** See Argillic horizon

## Abrupt textural change

Abrupt textural change refers to a boundary between an ochric epipedon (or albic horizon) and the underlying argillic horizon. A significant increase in clay is seen over a very short vertical distance in the zone of contact between the A or E horizon and the underlying horizon. This increase in clay should be twofold over 7.5 cm, if the clay content of the A or E horizon is less than 20%, and at least 20% if the clay content of the A or E horizon is greater than 20%.

## Abscisic acid

The name abscisic acid (ABA), a weak organic acid, is derived from the ability of a substance to promote abscission. **Abscission** is the natural detachment of leaves, branches, flowers, etc. from plants. Abscisic acid is a naturally occurring plant growth inhibitor, and is one of five major plant hormones. It carries out a number of important functions in the growth and development of

plants. It is a key factor controlling stomatal movements, leaf senescence and bud and seed dormancy.

Abscisic acid (ABA) is present in leaves, fruits and seeds, and is distributed throughout the plant body. The synthesis of ABA takes place mainly in **chloroplasts**. The rate of synthesis of ABA increases when the plant is under stress.

Chemically, abscisic acid is a member of the terpenoid family. The chemical structure of ABA is shown in Fig.A.2.

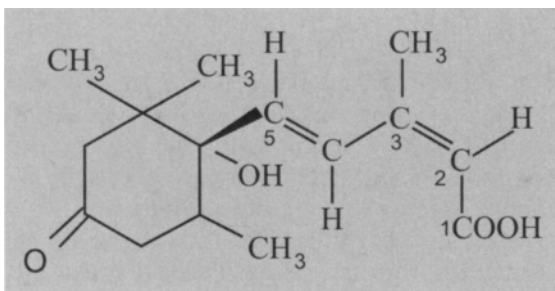


Fig.A.2: Structural formula of abscisic acid

## Abscission

Abscission is the natural detachment of leaves, branches, flowers, etc. Separation of an organ takes place due to the disintegration of the wall of the separation layer. Almost any part of the plant, from a small bud to branches of several inches in diameter can be abscised in some plant species. However, annuals tend to show little abscission, especially of leaves.

Abscission is useful in plants in many ways. It involves self-pruning, dispersal of seeds or other reproductive structures, and removing dead, injured or diseased parts.

Abscission facilitates recycling of mineral nutrients to the soil, thus maintaining a balance in leaves, roots, and in vegetative and reproductive parts. Generally, the process of abscission is restricted to the abscission zone of an organ (Fig.A.3). The portion of the abscission zone that remains attached to the plant, develops into a corky protective layer.

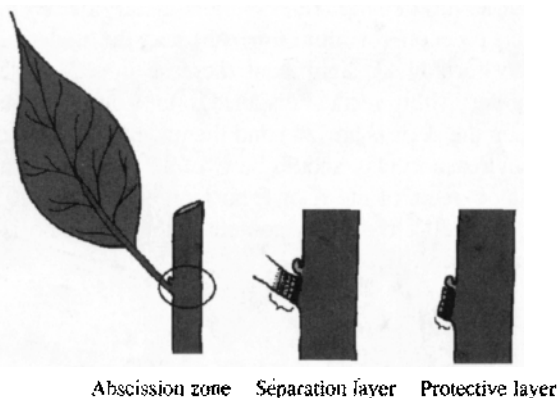


Fig.A.3: Abscission

When auxins are applied (as is done in experimental trials) to the distal side (organ) of the abscission zone, it retards abscission, whereas, when it is applied to the proximal side (stem), it accelerates abscission.

Gibberellin, a growth hormone, delays abscission. On application to young fruits or leaves, gibberellin promotes growth, delays maturation and ultimately prevents or delays abscission. Abscisic acid promotes abscission and senescence and can also retard plant growth. As a matter of interest, ethylene in small amounts can also distort and reduce plant growth and promote senescence and abscission.

## Absolute temperature

Absolute temperature denotes a temperature measured on an absolute scale. It is a temperature scale used in theoretical physics and chemistry and in engineering calculation.

Absolute temperatures are expressed in Kelvin or degrees Rankine corresponding to the centigrade and Fahrenheit scales respectively. Kelvin is obtained by adding 273.15 to the degree centigrade temperature (if above 0°C) and subtracting the degree centigrade temperature from 273.15 (if below 0°C). Degrees Rankine are obtained by subtracting 460 from the Fahrenheit temperature. The closest approach to absolute zero is -272°C.

## Absorbent

Any substance exhibiting the property of absorption is called an absorbent. Absorbent cotton, so made by the removal of natural waxes is one such example.

## Absorption

The process by which a solid or liquid takes up gas, or a solid takes up a liquid, is known as absorption.

The movement of a fluid or a dissolved substance across a cell membrane is also called absorption. In plants, water and nutrients are absorbed from the soil by the roots (Fig.A.4). This phenomenon is due to a combined effect of osmotic pressure within the plant cells, electrical charge of the absorbed ions, surface tension, permeability of the cell membranes, etc. The fixation of potassium ion between the layers of clay minerals, such as **illite**, is also due to absorption.

Absorption is different from **adsorption**. While the absorbed substance permeates the bulk of the absorbing substance, adsorption is a surface phenomenon.

The movement of ions and water into plant roots against the activity gradient is called **active absorption**, whereas the movement of water into the roots resulting from the pulling forces on the water column in the plants (to compensate for the water lost by transpiration) is called **passive absorption**.

**Absorption ratio of potassium:** See Potassium absorption ratio

## Abstraction license

Abstraction license is an authorization issued by a water authority to allow water to be drawn from a water source for irrigation and/or for commercial or domestic uses.



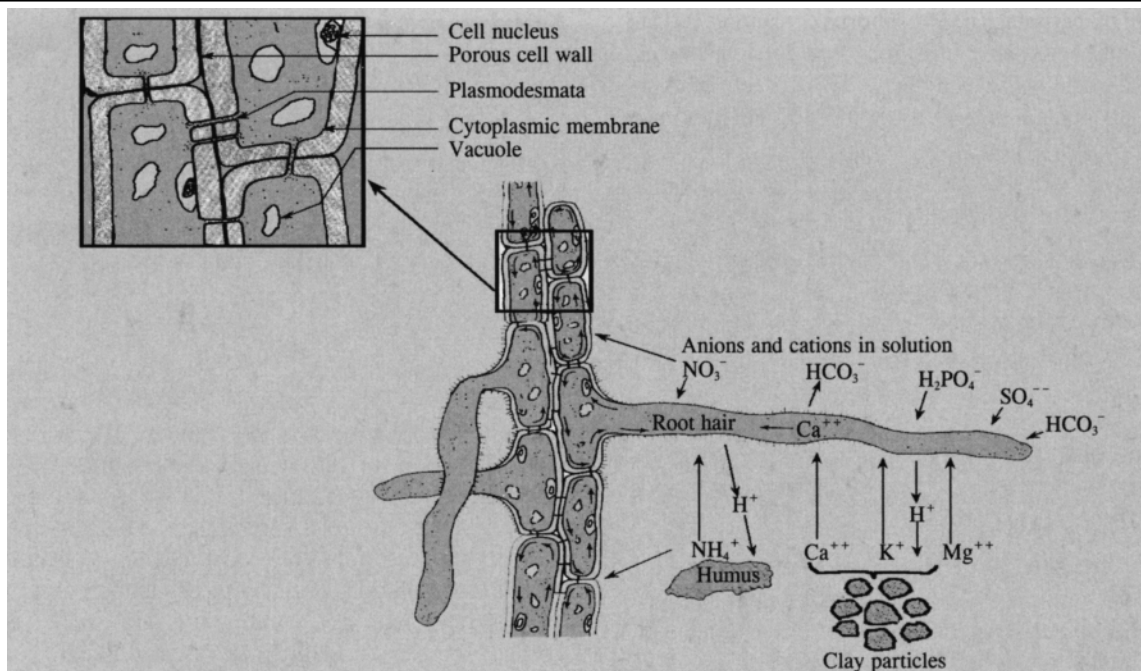


Fig.A.4: Diagrammatic representation of absorption of plant nutrients from the soil by plant roots. Inset: An enlarged portion of the root tissue.

### Accelerated caking test

The accelerated caking test is one of several tests to evaluate the caking tendency of fertilizers. (See Caking tendency, evaluation of.)

### Accelerated erosion

Accelerated erosion occurs when geological erosion (caused mainly by wind, water and heat) is accompanied by human activities, leading to the top soil being removed rapidly.

Accelerated erosion is rapid and often destructive. (See also Soil erosion.)

### Accelerator

The substance that accelerates the speed and output of a process is called an accelerator. (See also Activator.)

### Acceptable risk

Acceptable risk is a concept that has developed in recent times when environmental issues like air and water pollution, and the hazards of toxic substances (like insecticides and pesticides) have received greater focus. Acceptable risk is defined as the risk level at which a seriously adverse result is highly unlikely, but about which an assurance of 100% safety cannot be given. It means living with a reasonable assurance of safety and acceptable uncertainty. Diagnostic x-rays, fluoridation of water and ingestion of saccharin in small amounts are some examples of acceptable risks.

### Acceptance inspection

The inspection of a sample of raw material or of a finished product, based on some set criteria and procedures, which leads to inference of whether the

material or the product is acceptable or not, is called the acceptance inspection. The standards of acceptance inspection are set according to the product requirement at the user's end rather than by the inherent capabilities of the process.

### Accessory nutrients

Among the various nutrients essential for plants, there are some growth enhancing nutrients like vitamins, purines, pyrimidines and amino acids. These are called accessory nutrients. (See also Plant nutrients.)

### Accessory structural elements

Accessory structural elements are **nutrient elements** that form part of more active and vital living plant proteins (Fig.A.5). Some examples of this are the following: (i) Proteins contain nitrogen which constitutes

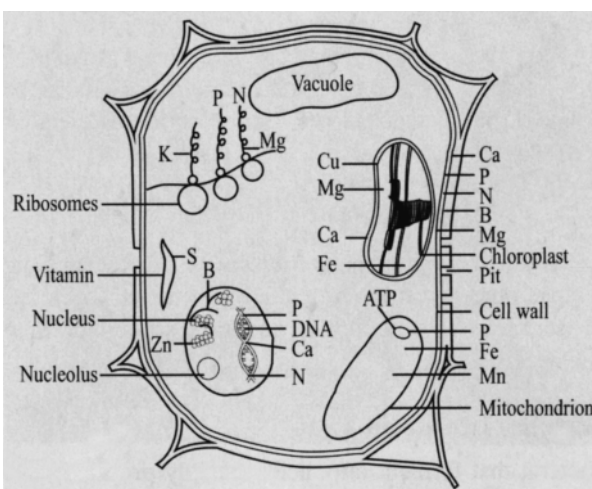


Fig.A.5: Diagrammatic representation of various nutrient elements in a plant cell.

1 to 3% of plant tissue. (ii) Phosphorus constitutes 0.05 to 1.0% of plant tissue and is found in nucleoproteins, phytin and lecithin. (iii) Sulphur is a constituent of many proteins. Its content varies from 0.05 to 1.50% in plant tissue.

### Acclimated micro-organism

An acclimated micro-organism has the ability to adapt to environmental changes, such as a change in temperature, pH, oxygen concentration, etc. Acid tolerant rhizobia are examples of acclimated micro-organisms.

**Accretion of soil:** See Soil accretion

### Accumulation layer

Materials leached from the upper soil layer are accumulated in the layer below. The layer that receives the leached material becomes the accumulation layer. The accumulation layer (or **accumulation zone**) or **illuvial layer** has a fairly high clay content. (See also Soil horizons.)

**Accumulation zone:** See Accumulation layer

### Accumulators

Plants which concentrate large quantities of elements such as selenium and aluminum in their tissues are known as accumulators. Such plants can be used for toxicity control as in bioremediation.

Among non-living materials, an accumulator is a voltaic cell or battery that can be recharged by passing current through it from an external D.C. supply. The charging current, passed in a direction opposite to that of the cell supplying the current, reverses the chemical reactions in the cell. Those using acid, nickel-iron and nickel-cadmium are among the common types of accumulators.

### *Acetobacter diazotrophicus*

*Acetobacter* (or *Gluconacetobacter*) *diazotrophicus* is a nitrogen fixing endophyte, very specific to sugar-rich crops. It tolerates acidic and nitric conditions and can be isolated from the soils, roots, stems and leaves of sugar cane and sweet sorghum.

### Acetoclastic bacteria

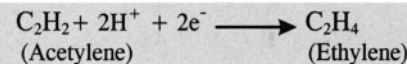
Bacteria that form methane exclusively from acetic acid in anaerobic digestion are called acetoclastic bacteria. These bacteria grow slowly and take several days to double.

### Acetogenic bacteria

Bacteria that ferment fatty acids (mainly propionic and butyric acids) to acetic acids are called acetogenic bacteria.

### Acetylene reduction assay

The biological reduction of dinitrogen ( $N\equiv N$ ) to ammonia ( $NH_3$ ) is carried out by prokaryotes in soil and plants with the help of the enzyme nitrogenase. Nitrogenase also reduces a variety of substrates like acetylene, nitrite, cyanide, etc. It also catalyzes the reduction of acetylene to ethylene. The end product ethylene is easily detected by gas chromatography.



The reduction of acetylene is only indicative of nitrogen fixation which has to be, however, confirmed by isotopic methodology or other methods. The theoretical ratio of 1 mole of nitrogen fixed per three moles of acetylene reduction cannot be used for quantifying the fixation as the ratios can vary widely. This is because a part of the electrons are diverted for concomitant hydrogen evolution. Acetylene reduction assay is therefore to be interpreted with caution and can be used in a limited sense to screen for putative diazotrophs.

The word assay refers to testing or determination of the quality, content or concentration of a substance. In an acetylene reduction assay, excited nodules, detached roots with nodules, whole plants or microbial suspensions are enclosed in a closed container in which 10% of the volume is replaced by acetylene. After incubation for a suitable period, the ethylene evolved is sampled and estimated by gas chromatography using a flame ionization detector. The rate of ethylene evolved is indicative of the nitrogen fixing potential of the system. Because of its simplicity, high specificity and sensitivity, low cost and short assay period, the method has been widely applied to detect nitrogen fixation in a whole range of systems ranging from purified nitrogenase components to legume-*Rhizobium* associations.

### Acid

Acids are one of the largest classes of chemicals whose aqueous solutions have one or more of the following properties: (a) sour taste, (b) ability to turn litmus paper red and cause other indicator dyes to change to characteristic colours, (c) ability to react with and dissolve some metals to form salts, and (d) ability to react with bases or alkali forming salts. All acids contain hydrogen. In water, acids ionize and form hydronium ions ( $H_3O^+$ ), usually written simply as hydrogen ions.

Acids are classified as strong acids or weak acids according to the concentration of hydrogen ions that results from ionization. Hydrochloric acid, sulphuric acid, nitric acid and perchloric acid are strong acids since they ionize almost completely in dilute aqueous solutions. Acetic acid and carbonic acid are weak acids. The pH range of acids is from 6.9 to 1 and is a measure of the acid character in an aqueous solution.

In solvents other than water, acid is defined as a substance that ionizes to release the positive ion of the solvent. The Lowry-Bronsted definition of an acid as a substance that can give up a proton is useful in the

understanding of a base. The most significant contribution to the theory of acids was the electron-pair concept enunciated by G. N. Lewis. According to Lewis, any molecule or ion that can combine with another molecule by forming a covalent bond with two electrons from the second molecule or ion is an acid. Thus, acid is an electron acceptor like  $\text{BF}_3$  or  $\text{AlCl}_3$ . The hydrogen ion is the simplest substance that will do this.

The terms 'hard' and 'soft' acids and bases refer to the ease with which their electron orbitals can be distorted. Hard acids have positive oxidation state, and their valence electrons are not readily excited. Soft acids have little or no positive charge and possess easily excited valence electrons. Hard acids combine with hard bases and soft acids with soft bases. Soft acids tend to accept electrons and form covalent bonds more readily than hard acids. For example, halogen acids show a progression from hard (HF) to soft (HI).

Major groups of acids are as follows:

- (i) Inorganic mineral acids like hydrochloric acid and phosphoric acid.
- (ii) Organic acids, whose four major groups are
  - (a) mono carboxylic acids which contain one COOH group (examples include acetic acid),
  - (b) dicarboxylic acid, which contain two COOH groups (examples include phthalic, sebacic and adipic acids),
  - (c) fatty acids which contain long chain COOH groups (examples include oleic, palmitic and stearic acids), and
  - (d) amino acids which contain  $\text{NH}_2$  and COOH groups (examples include glycine.)
 Organic acids can also be classified into (a) aliphatic acids, such as acetic acid and formic acid, and (b) aromatic acids, such as benzoic acid and salicylic acid.

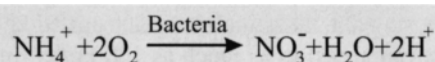
### Acid former

Acid formers constitute a group of facultative and obligate microbial anaerobes, capable of hydrolyzing and fermenting organic compounds (in sewage) to organic acids, like acetic acid and propionic acid. These microbes should, for better anaerobic sludge digestion, be in equilibrium with methanogenic bacteria.

The main acid formers (in view of their numbers in sludge compared to the facultative anaerobes) are **obligate anaerobes**.

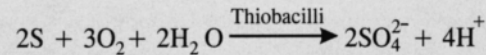
### Acid forming fertilizers

Chemical fertilizers are known for their acidity and basicity forming tendency. A fertilizer that leaves behind an acidic effect in the soil is an acid forming fertilizer. For example, bacteria oxidize ammonium-containing fertilizers like ammonium chloride, ammonium sulphate and urea to form nitrate and hydrogen ions, as shown below:



All fertilizers containing nitrogen, sulphur and phosphorus, and fertilizers lacking metallic cations belong to the category of acid forming fertilizers.

Sulphur, an ingredient of some fertilizers and fungicides, is oxidized to sulphate and hydrogen ions as:



The sulphate ion by itself is not acidic. The acidifying capacity of nitrogenous fertilizers varies widely. Some countries make it a mandatory requirement that the acid forming capability of fertilizers be specified in terms of calcium carbonate or lime required to neutralize the acidic effect (kg of lime/kg of nitrogen fertilizer.) This quantity of lime depends on the anions ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , etc.) present in the fertilizer as well as the amount of nitrate formed from oxidation of ammonium ions.

The quantity of calcium carbonate required to neutralize the acid residue of a fertilizer is its **equivalent acidity**. The theoretical equivalent acidity values of some fertilizers are given in Table-A.1.

Table-A.1: Theoretical equivalent acidity values of some nitrogenous fertilizers

Fertilizer	Equivalent acidity (kg of $\text{CaCO}_3$ per 100 kg of fertilizer)
Ammonium chloride	128
Ammonium phosphate (16% N + 20% $\text{P}_2\text{O}_5$ )	86
Ammonium sulphate	110
Ammonium sulphate-nitrate	93
Urea	84

### Acidic low moor peat

The acidic low moor peat is a highly decomposed raw material with pH less than 7 for peat fertilizers.

### Acidic soils

Soils with pH less than 7.0 are called acidic soils. Decomposing organic matter and root respiration produce carbon dioxide. This carbon dioxide dissolves in water and forms carbonic acid, which acidifies the water, and causes soil acidity. Soil acidity is determined by hydrogen ions ( $\text{H}^+$ ) or by the content of hydroxyl aluminum  $\text{Al}(\text{OH})^{2+}$  or aluminum ( $\text{Al}^{3+}$ ) ions. Ammonium nitrate, ammonium phosphate and ammonium sulphate-nitrate are among the **acid forming fertilizers**.

Bacteria oxidize ammonium-containing fertilizers to form nitrate and hydrogen ions. Some fertilizers and fungicides contain sulphur which is oxidized to sulphate and hydrogen ions. Some of these are excreted by plant roots, lowering the soil pH within the root zone.

Leaching increases soil acidity, albeit slowly, in soils with a high carbonate content. In highly industrialized areas, acid rain caused by the discharge of the oxides of sulphur and nitrogen to the atmosphere makes the soil acidic. Removal of the crop also makes the soil more acidic and depletes the reserves of calcium, magnesium and potassium.

Soil acidity can be corrected by several methods. Flooding the soil, for instance, raises the soil pH, although this is effective only for crops like lowland paddy that grows in waterlogged conditions. Another method is **liming**, which is to add alkaline material to acidic soils. Alkaline substances provide a conjugate base which reacts with hydrogen ions. (See also Soil acidity, correcting of; Liming materials.)

### Acidic stain

In the staining technique, if the color comes from a negative ion (organic anion), the stain is described as an acidic stain. For example, eosin. (See also Staining.)

### Acidimetry

The determination of the concentration of an acid in a solution or a mixture is called acidimetry. The acid character of soil is usually tested by titration with a solution of base of a known strength (standard solution.) An indicator is generally used to establish the end point.

### Acidity index

Acidity index is a term applied to commercial fertilizers which are left behind as a residue in the soil. The amount of calcium carbonate required to neutralize the acid residue in soil is known as its acidity index. It is the amount of calcium carbonate in kg required by 100 kg of a fertilizer.

Acidity index is an important chemical property of acid soils, which affects plant growth and nutrient uptake. (See also Base saturation.)

### Acidity quotient

Acidity quotient (AQ) is defined as the exchange in acidity ratio of litter, given by the ratio of exchange acidity of humus to that of the top horizon. It characterizes the influence of humus on soils. AQ of less than 1 indicates healthy soil.

### Acid neutralizing capacity

The acid neutralizing capacity (ANC) of a substance is given as the moles of protons per unit volume or the mass required for changing the pH of an aqueous system to a desired value at which the net charge from the ions not reacting with the hydroxyl ion ( $\text{OH}^-$ ) and hydrogen ion ( $\text{H}^+$ ) is zero.

ANC is expressed as:

$$\text{ANC} = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{OH}^-] - [\text{H}^+]$$

ANC increases as pH increases. The rate of change of ANC with pH ( $\text{dANC/dpH}$ ) is called the **buffer intensity**, BH. The buffer intensity of acid soils, found in the temperate zone which are rich in organic content, falls in the range of 0.1 to 1.5 mol/kg of organic matter per pH unit.

Proton budgets are estimated in terms of Kmol/hectare/year in field soil. Protons are produced by

release reactions (involving C, N and S) and by the bio-uptake of organic matter and carbon dioxide (aq). The protons are consumed in mineral weathering reactions such as hydrolysis, complexation and ion exchange, or may be lost due to inflow processes or deep percolation. If the production of protons is more than their consumption or loss, as is often the case in the tropics and in podzols in temperate regions, the soil becomes progressively acidic.

**Liming** is the time-honored method of mitigating soil acidity.

### Acidophilic cell components

In the staining technique, the cell components that are stained with acidic dyes are classified as acidophilic cell components. (See also Staining.)

### Acid peat

**Peat** is vegetable matter partly decomposed in wet acid conditions to form a brown deposit. The degree of decomposition and conversion of organic matter and the surrounding environment create different types of peat. Peat is used as fuel in gardening, etc.

Acid peat (oligotrophic) is of atmospheric origin. Over the ages, as bogs developed their own peculiar vegetation (like hazel, pine trees, reeds, moss, etc.), the decomposition of dead plant material led to the accumulation of peat in lake beds. This accumulation led to the stagnation of the lake, and made the peat and the water acidic in nature.

Acid peat is commonly added to soil that is not acidic. Acidic peat, sulphur or ferrous sulphate can help lower soil pH to 4.4.

### Acid phosphate of lime

Acid phosphate of lime is another name for **concentrated superphosphate**.

### Acid rain

Acid rain is rain that contains excessive concentration of acidic radicals like nitrate and sulphate. It is a major pollutant in Canada, Norway, Sweden, the United States and many highly industrialized countries. Millions of tons of sulphur dioxide and nitrogen oxide are discharged into the atmosphere as gaseous particles which are oxidized to sulphuric and nitric acids. When these oxides of sulphur and nitrogen get dissolved in atmospheric moisture, they cause acid rain. Similarly, sulphur dioxide and nitrogen oxides emitted in the atmosphere by forest fires and the burning of fossil fuels are converted into the respective acids and precipitated as acid rains.

Usually, the pH of rain water is 5.6 to 5.7, but that of acid rain can be as low as 2.0. The amount of dissolved sulphur during annual rainfall ranges from 10 kg/ha (in less industrial areas) to as much as 100 kg/ha (in highly industrialized areas).

Acid rain affects plant growth. It also damages foliage, impairs photosynthesis, destroys fish in lakes

and rivers, and affects marble, limestone and buildings (especially stone masonry constructions). Lichens are particularly sensitive to changes in pH and are used as indicators of acid pollution. In many developing countries, acid rain is caused by excessive burning of wood, coal and petroleum products.

Though oxides of sulphur and nitrogen are principal culprits in causing acid rain, emission of ammonia from livestock waste, fertilizer applications and industrial processes also contribute considerably to the formation of acid rain. Certain volatile organic compounds can also cause acid rain through photochemical reactions.

Acid rain is also known to lead to the dissolution of toxic metals like cadmium, copper and aluminum which otherwise remain adsorbed onto sesquioxides and humus.

### Acid sulphate soil

When sulphur-bearing iron pyrites present in acid soils (pH < 4) oxidize to form sulphuric acid, the soil gets converted into an acid sulphate soil. Such a continuous process of acid formation renders the soil impossible to reclaim.

In anaerobic conditions, acid sulphate soil contains relatively high amounts of sulphides, whereas in aerobic conditions, it contains high amounts of sulphates.

Acid sulphate soils, also called **cat clays**, are found especially in coastal belts and in estuarine and delta areas of the humid tropics. These are known as *Katteklei* (cat's coat) in The Netherlands. In India, acid sulphate soils occur in the states of Orissa, Kerala and West Bengal.

### Acidulated bone

A ground bone or a bone meal treated with sulphuric acid is called acidulated bone.

### Acidulated phosphate rock

A raw phosphate rock, treated with sulphuric acid is called acidulated phosphate rock. (See also Single super phosphate.)

### Acidulated superphosphate

Acidulated superphosphate is a superphosphate formed from acidulation of phosphate rock with sulphuric acid.

### Acidulating the soil

Any substance treated with acid is said to be **acidulated**. To make superphosphate fertilizer, phosphate rocks are acidulated with sulphuric acid. A ground bone or bone meal treated with sulphuric acid is called **acidulated bone**.

Generally, moderately acidic soil is better suited to plants than neutral or basic soils. When soil is inherently high in carbonates, as in arid and semi-arid regions, some amount of acidification improves plant growth.

The acidulation of paddy soil increases rice yields by increasing the availability of micronutrients. Similarly,

acidification increases the production of potatoes, blueberries, cranberries, azaleas, rhododendrons, camellias and conifer seedlings.

For acidulation, several acidic or acid forming materials (like elemental sulphur, iron pyrites, sulphuric acid and aluminum compounds) are used. Sulphur in elemental or suspension form is the most effective soil acidulant, if applied several weeks before planting a crop. The microbial oxidation reaction may be slower in alkaline soils, especially in cold seasons. Less sulphur is required when applied in band mode than when broadcast.

Sulphuric acid is used for (a) reclaiming the soils affected by sodium or boron, (b) increasing the availability of phosphorus and micronutrients, (c) reducing ammonia volatilization, (d) increasing water penetration, (e) controlling certain weeds and soil-borne pathogens, and (f) enhancing range grasses. It can be dribbled on the surface of the soil, applied in ditch irrigation water or applied with a knife applicator.

Aluminum sulphate is also used for acidulating soils. Liquid ammonium sulphide, when applied in bands or through irrigation water, decreases soil pH and increases the water penetration in saline-alkali irrigated soils. Ammonium polyphosphate and ammonium thiosulphate solution acidify the soil in and near the band and increase micronutrient availability.

### Acidulation

The treatment of any substance with an acid is called acidulation. For example, phosphate rock is acidulated with sulphuric acid to make superphosphate fertilizer.

### Acid value

Acid value is known as the number of milligrams of potassium hydroxide required to neutralize the free acids present in one gram of substances like soil, fat, oil, etc. Acid value is determined by the titration of a known quantity of the sample in aqueous solution or KCl solution for soils, and hot 95% alcohol for oils and fats using phenolphthalein as an indicator.

### Acquifers

Geological formations like sand, gravel or any porous rock that transmit water underground are called aquifers. (See also Ground water.)

### Acre-inch-day

Acre-inch-day is a measure of the quantity of water flow covering one acre of land to a depth of one inch in 24 hours or 0.042 cu ft/sec. This unit is used mainly in the USA.

### Acrisols

In the FAO/UNESCO system of soil taxonomy, intensely acidic soils with a low base saturation are called acrisols.

### Acropetal translocation of fungicides

Acropetal is a botanical term which means "developing from below upwards". **Translocation** here means transport of a dissolved substance within an organism, especially in the phloem of a plant or actively across a cell membrane. For instance, when a fungicide enters plant tissues and is transported upwards, the phenomenon is called acropetal translocation of the fungicide.

### Actin

Actin and myosin are the principal fibrous proteins of muscle; their interaction brings about muscle contraction. (See also Protein.)

### Actinomycetales

Actinomycetales is a bacterial order. Filamentous bacteria, called **actinomycetes**, come under this order.

### Actinomycetes

Actinomycetes are filamentous micro-organisms that are intermediate between bacteria and fungi. They have a mass of fine elongated threads called **mycelium**, which resembles the typical growth structure of fungi. They reproduce asexually by fission, or through spores. Actinomycetes means ray fungi because of the mycelia, but they are distinct from fungi in many ways. Actinomycetes come under the bacterial order of **actinomycetales** and belong to the phyla Actinobacteria. Like bacteria, actinomycetes secrete some polysaccharides and help retention of water in soils. Their cell wall is typical of bacteria. They are **prokaryotic**, which means that their genetic material is not enclosed in the cell nucleus. Most actinomycetes are aerobic and help decompose organic matter, like cellulose and other resistant organic molecules. The characteristic odor of a freshly plowed moist field is due to soil actinomycetes. A very few of the actinomycetes establish symbiotic nitrogen fixing association with plants like soapberry, alders, bitterbrush, coffee berry, Australian pine, mountain mahoganies, etc.

Actinomycetes are helpful to at least seven botanical families. Actinomycetes help in the synthesis of a great variety of antibiotics like streptomycin, aureomycin, terramycin and neomycin.

While actinomycetes can survive in soils with low moisture, they develop best in moist and well-aerated soils.

### Activated sewage products

Activated sewage products are obtained from aerated, flocculated organic matter, inoculated with micro-organisms. The dried organic matter when ground, screened and bagged is used as a fertilizer.

### Activated sludge

**Sludge**, when subjected to microbial action, becomes a **biologically active substance** and is called activated

sludge. It is a solid-liquid viscous mixture which is soft, thick, wet or muddy. Domestic sewage containing more than 20% solid is also called sludge. Similarly, industrial organic wastes from processes such as alcohol distillation, paper making, meat packing, flour making and petroleum refining are also called sludge. Some of these residues contain excessively high sodium while others contain toxic substances.

A mixture of organic materials resulting from the purification of municipal waste contains both macronutrients and micronutrients. There are two types of this sludge: (i) **Imhoff sludge** - which is a low-grade sludge containing 2 to 3% ammonia and about 1% phosphoric acid. (ii) **Activated sludge** - which is a high-grade sludge containing 5.0 to 7.5% ammonia and 2.5 to 4.0% phosphoric acid. These are derived from running sewage through settling tanks, without access to air, and then leaving it to decompose anaerobically. After the activated sludge treatment, lagooning may be used effectively. Activated sludge is also derived by pumping air or oxygen through porous plates at the bottom of the settling tanks. Twenty percent of the sludge is added as a nutrient for aerobic bacteria. The resulting solids are filtered and dried. The dried sludge is used as a fertilizer. Repeated exposure to atmospheric oxygen by mechanical infusion of air into the sewage increases bacterial activity in the sludge. This product is good for land use as its plant nutrient content ranges from 3 to 6% N, 2 to 4% P<sub>2</sub>O<sub>5</sub> and 0.5 to 1.5% K<sub>2</sub>O.

The sewage and septage residues, along with industrial waste, can replace chemical fertilizers equivalent to about 1% of nitrogen, 4% of phosphorus and 0.5% of potassium. This amounts, on a dry weight basis, to roughly 4% nitrogen, 2% phosphorus and 0.4% potassium, irrespective of the chemical composition of the sludge.

Sludge often contains toxic heavy metals such as boron, cadmium, copper, mercury, nickel, lead, selenium and zinc as well as phytotoxins, pesticides or other toxic compounds. **Sewage sludge** may carry pathogens and infectious agents responsible for cholera, diarrhoea, hepatitis, helminth parasites, poliomyelitis and tapeworms. To reduce the pathogenic hazards from sludge, many techniques are used which are as follows: (a) composting outside the soil for at least 21 days, (b) storage as a semi-liquid, anaerobically digested for at least 60 days at 20°C, or 120 days at 40°C, or a combination thereof, (c) treatment, when moist, with lime for at least 3 hours, and (d) pasteurization for 30 minutes at 70°C.

The quantity of sludge to be applied annually depends on the lowest tonnage needed to meet the nitrogen requirement of the crop or the quantity that can be used by the crop without making it toxic for the plant.

Sludge is used for crops like forages, oilseeds, small grains, commercial sod (turf grass) and trees. It is, however, not used for root crops, vegetables, fruits, tobacco and dairy pastures. Crops respond to sewage sludge as they do to a commercial fertilizer in the first year of application; the response may get better in



subsequent years because of the residual effect of the added plant nutrients. Many physical properties of the soil (such as the water and nutrient holding capacity, infiltration, aggregation) are seen to improve with the application of sludge. Repeated application of large quantities of sludge (>10 t/ha) may cause 'soil sickness'.

### Activator

Generally, an activator or **accelerator** is a substance that activates, accelerates or increases the total output of a process. Microbial cultures added to organic materials or residues to hasten their decomposition act as **biological accelerators**. These microbial cultures include fungi like *Aspergillus* sp., *Paecilomyces fusisporus*, *Trichurus spiralis*, *Trichoderma viride* and other phosphate solubilizers (Fig.A.6).

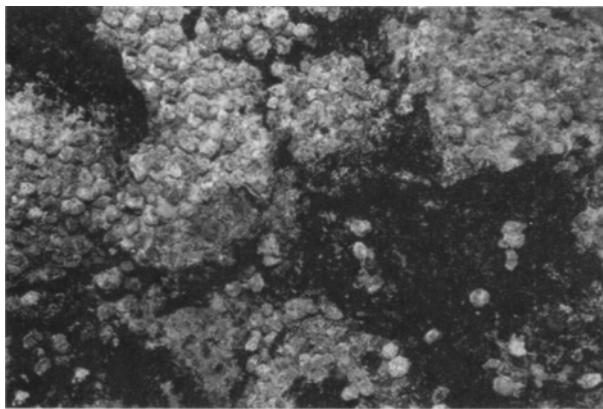


Fig.A.6: Growth of various compost accelerators is evident as differently colored colonies on the medium.

Metallic oxides (like zinc oxide), which promote cross-linking of sulphur in rubber vulcanization are other examples of accelerators. Similarly, oxides of magnesium, calcium or lead are also effective accelerators when mixed with rubber. Organic accelerators should ideally not be added to this mixture.

Stearic acid, along with thiazoles, increases the effectiveness of acidic organic accelerators. Any trace amount of a substance, required to induce luminescence in certain crystals, is also an accelerator. Silver and copper activate zinc sulphide and cadmium sulphide.

### Active absorption

The movement of ions and water into plant roots against the activity gradient is called active absorption.

### Active acidity

Active acidity is one of the two types of acidity. (See also Reserve acidity.)

**Active biomass** : See Biomass

### Active calcium carbonate

Active calcium carbonate is a fine form of lime which is readily soluble in carbonated water. It enriches soil solutions with bicarbonate that progressively saturates

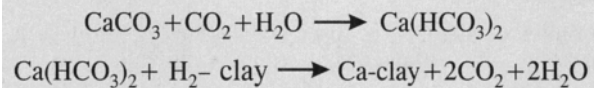
the adsorption complex of clay-type soils. In contrast, active calcium carbonate renders iron insoluble in carbonated water.

### Active ion uptake

When ions move against a concentration gradient, it is called an active ion uptake. (See also Ion uptake, active and passive.)

### Active lime

Active lime is a fine form of lime. It is readily soluble in water containing carbon dioxide. It enriches soil solutions with soluble bicarbonate, which progressively saturates the adsorption complex of the soil with a high content of clay.



Active lime is insoluble in lime-rich soils, leading to lime chlorosis. Chlorosis, caused by iron deficiency, makes plant leaves lose their color abnormally. Chlorosis is common in those soils of Northern Africa, which are rich in active lime. Peach, chestnut and oak do not tolerate active lime.

Lime activity is determined by the **Drouinean method** in which lime is treated with excess ammonium oxalate. Calcium oxalate precipitates from the active lime and the excess oxalate of ammonium is determined by titration with potassium permanganate. This method is applicable usually to soils containing more than 8% total lime.

### Activity index

Activity index (**AI**) is a measure of the suitability of slow nitrogen releasing substances, as a nitrogen fertilizer. An example of such a substance is urea-formaldehyde-ureaform. The activity index is defined as :

$$\text{AI} = \frac{\% \text{CWIN} - \% \text{HWIN}}{\% \text{CWIN}} \times 100$$

where CWIN is the cold water insoluble nitrogen (25°C) and HWIN is the hot water insoluble nitrogen (98 to 100°C.)

**Ureaform** contains about 38% nitrogen, a fraction of which is cold water insoluble and another fraction is hot water insoluble. For ureaform to be effective as a nitrogen fertilizer, the AI should be at least 40, according to American Association of Plant Food Control Officials (AAPFCO).

### Activity ratio

Activity ratio is the ratio of the activity of two types or species of cations in an equilibrium solution. Plants take up potassium ions from the aqueous liquid phase of soil and its solutes. The concentration of potassium ions in the soil solution depends mainly on the crop, its type and

growth. The optimum potassium level varies between 10 and 60 ppm depending on the crop, the soil texture, overall fertility level and moisture content.

The effectiveness of soil potassium for a crop uptake is influenced by the presence of other cations like calcium and magnesium. Aluminum cations (in acidic soils) and sodium ions (in salt affected soils) may also influence the uptake of soil potassium by the crop.

The activity ratio of potassium ( $AR^k$ ) in solution in equilibrium with soil is given by:

$$AR^k = \frac{a_k}{\sqrt{a_{(Ca+Mg)}}}$$

where  $a_k$  is the activity of potassium ion and  $a_{(Ca+Mg)}$  is the activity of calcium and magnesium cations.  $AR^k$  provides a satisfactory estimate of the availability of potassium. The activity ratio is also a measure of labile potassium in soil and gives the amount available to the crop roots.

To describe the soil status, it is necessary to specify not only the current potential of potassium in the labile pool but also the way the intensity depends on the quantity of labile potassium present through multiple measurements. The relation between exchangeable potassium ions (Quantity, Q) and the activity of solution potassium cation (Intensity, I) is a good measure of the status of potassium in the soil and the availability of more labile potassium in that soil. The ability of a soil to maintain the activity ratio against depletion by leaching is governed partly by three factors: the labile potassium pool, the rate of release of the fixed potassium, and the diffusion and transport of potassium ions in the soil solution. Usually, a neutral (normal) ammonium acetate solution is a good extractant for exchangeable soil potassium.

### Activity ratio of potassium

The activity ratio of potassium is the ratio of the activity of potassium in soil extract to irrigation water, which shows the relative activity of potassium ions in the exchange reactions with soil.

### Actomag

Actomag is a trade name for a selectively calcined dolomite produced by a patented US process. When dolomite is calcined at an appropriate temperature, magnesium carbonate ( $MgCO_3$ ) is decomposed, leaving behind magnesium oxide ( $MgO$ , 27%) and nearly intact calcium carbonate ( $CaCO_3$ , 67%).

### Actual acidity

Actual acidity is a type of acidity, determined by the hydrogen ion concentration in a solution as measured by the hydrogen-ion electrode. (See also pH.)

### Acute toxicity

Acute toxicity refers to the ability of a substance to cause damage to a living tissue or impairment to the central

nervous system or severe illness (leading in extreme cases to death) when ingested, inhaled or absorbed by the skin. The amount required to produce these results varies widely from substance to substance and the duration of its exposure to the living creature.

Acute toxicity is evidenced during short exposure that is a single, brief exposure: **chronic toxicity** refers to long-term exposure.

### Additive

An additive is a substance which is added to another material to improve the properties of the latter. Additives are often added in small amounts. For example, a small quantity of kaolin or talc is added to ammonium nitrate granules or prills to make them free flowing. Similarly, 0.3 to 0.4% formaldehyde is added to urea to make urea abrasion resistant.

### Adenosine diphosphate

Adenosine diphosphate (ADP) is a phosphorus compound formed during the breakdown of **adenosine triphosphate (ATP)** by dephosphorylation. It is made of adenine, ribose, five carbon sugars and two phosphate groups (Fig.A.7). ADP acts as a source of energy in biochemical reactions.

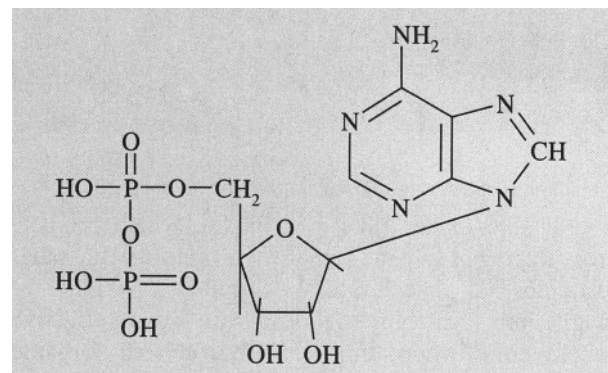


Fig.A.7: Structure of ADP.

### Adenosine monophosphate

Adenosine monophosphate (AMP) is a phosphate compound (Fig.A.8) formed by the hydrolysis of covalent bonds of **adenosine triphosphate (ATP)** molecules (linking to adenosine and 3-phosphate groups by N-glycosidic linkage and phosphodiester bonds respectively), by the process of dephosphorylation.

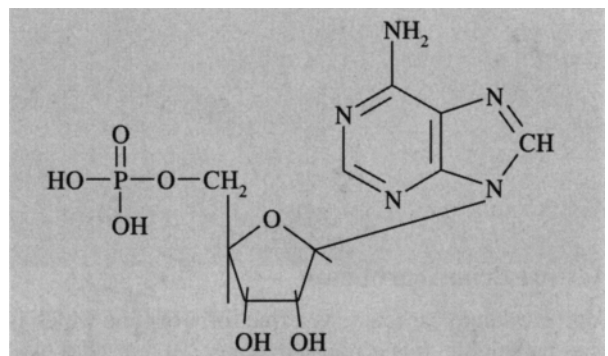


Fig.A.8: Structure of AMP.



## Adenosine triphosphate

Adenosine triphosphate (ATP) is a nucleotide of fundamental importance as a carrier of chemical energy in all living organisms. The most important function of phosphorus in a plant system is to store and transfer energy. During biochemical processes, ATP (Fig.A.9) gets synthesized to store releasable energy with the breakdown of ATP to **adenosine diphosphate (ADP)** and to phosphate ion by dephosphorylation. Here, ADP and ATP act as energy currency within the plant.

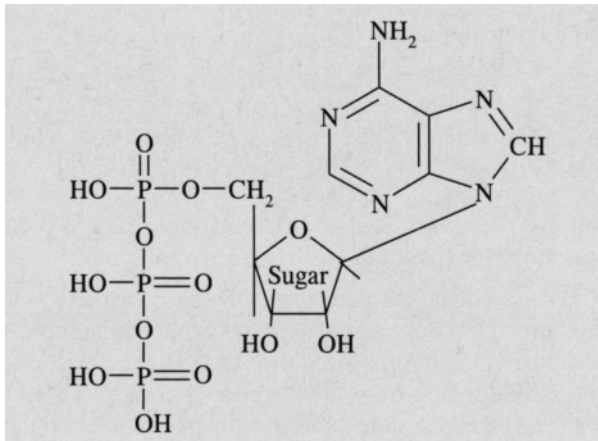


Fig.A.9: Structure of ATP.

In the ATP molecule, deoxyribose is linked covalently to adenosine (through an N-glycosidic linkage) and to three phosphate groups. These phosphodiester bonds are sequentially hydrolyzed to yield an ADP molecule and an inorganic phosphate, or a molecule each of **adenosine monophosphate (AMP)** and pyrophosphate, by dephosphorylation. Both reactions yield a large quantity of energy (about 30.6 kJ/mole) that is used to bring about muscle contraction as well as active transport of ions and molecules across the cell membrane, and synthesis of the biomolecules. The reactions bringing about these phenomena often involve an enzyme-catalyzed transfer of the phosphate group to intermediate substrates. Most ATP mediated reactions require magnesium ions as cofactors.

ATP is generated by the phosphorylation of AMP and ADP in the presence of sufficient phosphorus, which uses chemical energy obtained from oxidation of food. This takes place during glycolysis and the **Krebs cycle** but most significantly it is also a result of oxidation-reduction (**Redox reactions**) of the electron transfer chain that finally reduces molecular oxygen to water. Almost every metabolic reaction of any significance proceeds via phosphate derivatives.

## Adhesion

Adhesion, the act of sticking together, involves mutual bonding caused by an attraction between surface molecules of two different substances placed in contact. There can be adhesion between two liquids, two solids, or a liquid and a solid. The inter-facial forces acting here may consist of valence forces or interlocking action or both.

The separation of two different phases (A and B) requires energy. Adhesion is measured as a force or work necessary to separate the two phases with unit interface area. The work necessary to tear off the adhesion ( $W_a$ ) when the two phases share an interface area of  $1 \text{ m}^2$  is:

$$W_a = \sigma_A + \sigma_B - \sigma_{AB}$$

where  $\sigma_A$  and  $\sigma_B$  are the surface energies of the two surfaces,  $\sigma_{AB}$  is the surface energy of the interface between A and B.

When a liquid is in contact with an insoluble solid, three kinds of surface energy exist: (a) between the liquid and the gaseous phase, (b) between the solid and the gaseous phase, and (c) between the solid and the liquid phase. The work of adhesion is calculated from:

$$W_a = \sigma_L (1 + \cos \theta)$$

where  $\sigma_L$  is the surface energy at the liquid-air interface and  $\theta$  is the angle of wetting.

The mutual attraction between molecules of the same substance is called **cohesion**. Synthetic soil conditioners facilitate the cohesion of micro-aggregates into macro-aggregates.

In the case of a fertilizer, its particles can cake or agglomerate on storage due to adhesion, leading to poor flow. Such caking or lumping makes fertilizer application difficult.

## Adhesive contacts in fertilizer caking

As a result of molecular attraction, adhesive contacts (**capillary adhesion**) are formed between the surfaces in contact; the forces of attraction are known as **van der Waals forces**. Such a contact is influenced mostly by the plasticity of particles and the pressure exerted on the material (fertilizer) when stored in bulk.

## Adjusted SAR

Adjusted SAR is short for **adjusted sodium adsorption ratio**.

## Adjusted sodium adsorption ratio

Sodium adsorption ratio (**SAR**) represents the tendency of sodium to increase its proportion on the cation exchange sites at the expense of the other types of cations. SAR is given by the ratio of sodium content to the content of calcium plus magnesium in water. When water contains bicarbonate ( $\text{HCO}_3^-$ ) and carbonate ( $\text{CO}_3^{2-}$ ) ions, they precipitate calcium and magnesium ions which increase the SAR value. Acidic waters can dissolve solid carbonates and bicarbonates, which in turn form carbonates of calcium and magnesium. The new formula, taking into account these changes, is known as the adjusted SAR. It is given by the following equations:

$$\text{Adj SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \times [1 + 8.4 - \text{pH}]$$

$$pH_c = (pk_2^I - pK_c^I) + p(\text{HCO}_3^- + \text{CO}_3^{2-}) + p(\text{Ca}^{2+} + \text{Mg}^{2+})$$

where  $(pk_2^I - pK_c^I)$  is essentially the Ca, Mg and Na ion concentration,  $p(\text{HCO}_3^- + \text{CO}_3^{2-})$  is the carbonate and bicarbonate concentration,  $p(\text{Ca}^{2+} + \text{Mg}^{2+})$  is the concentration of calcium and magnesium ions.

### Adjuvant

Adjuvant in general means something helpful or auxiliary. It is a substance that enhances the body's immune response to an antigen. When added to the main composition, the adjuvant improves the functioning of the main ingredient; the characteristics of the latter can change - in terms of improved wetting, reduced evaporation, increased penetration, better translocation, better weathering characteristics, retarded nutrient release, better pH adjustment, enhanced deposition and compatibility and reduced odor.

There are four types of adjuvants, namely (a) **surfactants**, (b) **oils**, (c) **drift retardant**, and (d) others.

Surfactant adjuvant molecules have a lipophilic and a hydrophilic phase. The former usually consists of a long-chain hydrocarbon or a benzene ring structure that has very low solubility in water but high solubility in oil, the latter having a high affinity for water. From the structure of the hydrophilic phase, three classes of surfactants are recognized, namely, anionic surfactants, cationic surfactants and non-ionic surfactants. In agriculture, the most commonly used surfactants are non-ionic which are non-toxic, easy to use and not affected by hard water.

The following are examples of the three surfactant classes: (i) **Anionic surfactants** - Sodium stearate  $\text{C}_{17}\text{H}_{35}\text{COO}^-\text{Na}^+$ . (ii) **Cationic surfactants** - Cetyltrimethyl ammonium bromide  $\text{C}_{16}\text{H}_{33}(\text{CH}_3)_3\text{N}^+\text{Br}^-$ . (iii) **Non-ionic surfactants** (Fig.A.10) - Poly (ethylene oxide) lauryl alcohol  $\text{C}_{12}\text{H}_{25}\text{O}(\text{CH}_2\text{CH}_2\text{O})_{23}\text{H}$ .

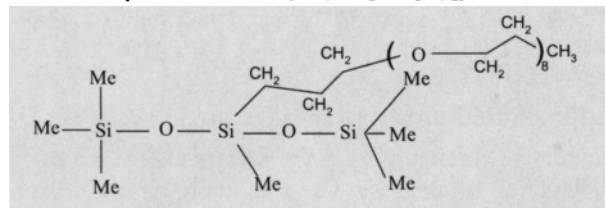


Fig.A.10: A new form of silicone type, non-ionic surfactant.

Surfactants have different uses as wetting and/or dispersing agents, emulsifiers, foaming agents, detergents, etc. A wetting agent (<0.1%) is added to herbicide sprays to make the droplets spread evenly over leaves, thus increasing the coverage and eventual uptake of the herbicide.

Exhaustive research on surfactants has revealed that a specific surfactant is ideal for a specific herbicide on a particular species. In recent times, formulations containing phytobland oils and highly concentrated (4 to 10%) surfactants are gaining increased popularity. These products are more effective in improving herbicide

retention and uptake than the surfactant alone. For some herbicides, the amount to be applied (usually around 2 liters/ha) is displayed on the label.

Oil adjuvants have been used in herbicide sprays for many years and are divided into 3 types. (i) **Phytotoxic, non selective adjuvants in herbicides**: These are highly unsaturated (for example, diesel and oil) and readily sulphonated, giving them a low unsulphonatable residue character. Oils of this category are added to the knock-down type herbicides to facilitate uptake through the bark for spraying canals and ditch-banks or to brush killers. (ii) **Phytotoxic, selective adjuvants in herbicides**: These are not actually adjuvants and may be sprayed directly without mixing with water or in combination with herbicides. (iii) **Phytobland oil-water emulsions**: These are nearly saturated light oils. They are not phytotoxic and are added to herbicides for better penetration in foliage. These are called by different names, such as **corn oils**, **superior spray oils**, **supreme spray oils**, etc.

When a liquid is forced through a spray orifice under pressure, a large number of extremely fine spray droplets accompany the normal sized droplets. These 'fines' can be easily diverted from the target area even by a slight breeze. If the herbicide is sufficiently phytotoxic and the breeze is sufficiently strong or if the fines produced are substantial, the fines can seriously damage non-target plants and crops. A long chain polymer, such as anionic polyacrylamide, can be added to the spray tank to reduce the number of fines and to serve as a **drift retardant**.

**Miscellaneous adjuvants** include (a) foaming agents which are often used to generate a glob of foam at either end of the spray boom to serve as a marker, (b) emetics which cause immediate vomiting to reduce the hazard of accidental ingestion, and (c) stench creating agents added to a toxic pesticide to prevent it from being mistaken for a soft drink.

### Adoption

Adoption, in the present context refers to the acceptance and implementation of an improved or a new technique related to farming, such as, a specific method of use of fertilizer or irrigation, by a farmer.

### ADP

ADP is short for **adenosine diphosphate**.

### Adsali sugar cane

**Adsali** sugar cane refers to the cropping pattern of sugar cane in which the crop (with a span of 18 months) is planted between June and August and harvested the next year from December to February. This pattern of sugar cane planting is common in the Indian states of Andhra Pradesh, Karnataka and Maharashtra.

### Adsorbate

A substance that accumulates in a two-dimensional molecular arrangement at the interface is known as an adsorbate.

## Adsorbent

The solid surface on which a substance (adsorbate) accumulates is called an adsorbent. Activated carbon, activated alumina and silica gel are examples of adsorbents.

## Adsorption

The formation of a layer of gas, liquid or solid molecules on the surface of a solid or liquid is known as adsorption. The process is always accompanied by the evolution of heat, which is called the **heat of adsorption**. The opposite of adsorption is a process called **desorption**. A substance accumulating in two-dimensional molecular arrangements at the interface is called an **adsorbate**, whereas the solid surface on which it accumulates is called the **adsorbent**. A molecule or an ion in the soil solution that can potentially be adsorbed is known as an **adsorptive**. Organic and inorganic colloidal materials in soil adsorb other substances (such as added fertilizers), and form an **adsorption complex**. In comparison, non-colloidal substances like sand and silt have no adsorption capacity.

Depending on the nature of forces involved, adsorption is divided into two types – chemisorption and physisorption. In **chemisorption**, a single layer of molecules, atoms or ions is held to the adsorbent surface by chemical bonds. In **physisorption**, adsorbed molecules are held by the weaker **van der Waals forces**. In addition, adsorption caused by electrical attraction of the ions to a charged surface is known as **electrostatic adsorption**.

The quantity adsorbed depends on the (a) pressure (concentration) at a constant temperature illustrated by the **adsorption isotherm**, (b) temperature at a constant pressure which is expressed by the **adsorption isobar**, and (c) effect of pressure on temperature at a constant amount adsorbed which is called the **adsorption isostere**. The cause (energy or power) of adsorption is called **adsorptive force**.

Compared to a pure solvent, surface-active substances accumulate on the surface and reduce the surface energy of the solution. Bonding of ions or compounds to the surface of a solid or liquid, which is usually temporary, is similar to the bonding of a calcium ion held on the surface of a clay crystal.

Adsorption is an important feature of surface reactions, such as those involving corrosion and heterogeneous catalysis. The property is also utilized in adsorption chromatography. The incorporation of oxyanions like borate, phosphate or molybdate into secondary metal oxides like that of Fe, Al and Mn, and of transition metals like Fe or Ni into the soil organic matter are examples of adsorption.

## Adsorption coefficient

Irving Langmuir developed the concept of monolayer adsorption of gases on surfaces from the kinetic theory of gases. The concept, known as **Langmuir isotherm**,

relates the amount of gas adsorbed at a plain solid surface to the pressure of gas in equilibrium with the surface.

The derivation of Langmuir isotherm assumes that (a) the adsorption is restricted to a surface monolayer which is energetically uniform, and (b) there is no interaction between the adsorbed species. The following equation shows that the fraction (q) of the surface covered by the adsorbate at a gas pressure (p) is given by:

$$q = \frac{bp}{1 + bp}$$

where 'b' is a constant called the adsorption coefficient, which is the equilibrium constant for the adsorption process.

## Adsorption complex

Substances like fertilizers adsorb on organic and inorganic colloidal materials in the soil to form an adsorption complex.

## Adsorption, electrostatic

Adsorption caused by electrical attraction of ions to a charged surface is known as **electrostatic adsorption**.

## Adsorption isobar

The quantity of substances adsorbed by a solid depends on its temperature at a constant pressure, and is expressed as its adsorption isobar.

## Adsorption isostere

The effect of pressure on the temperature of adsorption at a fixed surface coverage is expressed as the adsorption isostere.

## Adsorption isotherm

The quantity of substances adsorbed depends on the pressure or the concentration at a constant temperature, and is expressed as adsorption isotherm.

## Adsorption mechanisms

Adsorption involves holding molecules of a gas or liquid solute as a thin film on the outer or inner surface of the material. This can occur by three mechanisms, namely, diffusion, ion outer-sphere complex and inner-sphere complex.

A solvated ion neutralizes the surface charge in a delocalized way and is adsorbed in the diffused ion swarm so that fully dissociated ions from the functional group are free to move about in the soil solution. In the second mechanism, the outer-sphere surface complex has a cation solvation shell and the bonding is exclusively electrostatic. Finally, the inner-sphere complex mechanism involves a siloxane cavity and is likely to involve both ionic and covalent bonds. Covalent bonding varies with electron configurations of both the surface groups and the complexed ion; the inner-sphere surface complex is hence considered as the molecular basis of the term **specific adsorption**.

Specific adsorption, which is usually chemical, is selective for a particular ion or substance. Similarly, diffuse ion association and outer-sphere surface complexation have the molecular basis of the term **non-specific adsorption**, wherein the prefix 'non-specific' implies near non-dependence on the electron configuration of the surface group and the adsorbed ion.

Soil solution composition determines the relative affinity of a given metal cation to a soil adsorbent. The interactive strength among the three adsorption mechanisms decreases in the order of inner-sphere complex, outer-sphere complex and diffuse ion swarm.

### Adsorption, specific

Specific adsorption of an ion on a particular surface or substance is called specific adsorption. (See also Adsorption mechanisms.)

### Adsorptive

A molecule or an ion in soil solution that can potentially be adsorbed is known as an adsorptive.

### Adsorptive force

The energy or power of adsorption is called adsorptive force.

### Adulteration of fertilizers

Adulteration of fertilizers involves the practice of adding extraneous material to a standard fertilizer to lower its quality. A fertilizer is said to be adulterated when (a) it contains harmful or deleterious ingredients or unwanted crop or weed seeds in quantities sufficient to harm the plant when applied according to the directions on the label, (b) its composition differs from that given on the label, and/or (c) useless materials like salt or sand are added to it.

### Adventitious roots

Adventitious roots are those that appear on plant parts like stems, branches or even leaves. These are also called **central permanent** in crops like cereals, since they arise from crown internodes just below the surface of the soil. The same crown internodes are also the place of origin of shoots or parts above the ground. The banyan tree has adventitious roots.

### AEC

AEC is short for **anion exchange capacity**.

### Aeolian soil

The word aeolian means 'arising from the action of the wind'. Wind-transported soil material forms aeolian soil. **Loess and dunes** are examples of aeolian soils.

Loess is a material finer than sand. It can be transported and deposited by wind to great distances. Loess soils have neutral pH, well-balanced content of clay and organic matter, and are rich in plant nutrients.

They possess a high nutrient storage capacity and are, therefore, productive.

Loess soils, which are mostly silt, have unique properties. For instance, they (a) are open and porous, (b) have vertical cuts more stable than the slopes, and (c) can have problems (like the formation of sinkholes, cavities and subsurface channel cutting) when used for earthen dams. There are large areas of loess in countries like Argentina, China, Germany and the United States.

### Aeration factor

Aerobic micro-organisms need oxygen for respiration. The ratio of oxygen consumed by microbes in soil under optimum respiratory conditions (artificially created) to that consumed by them in the soil under natural conditions is the aeration factor expressed as a percentage. However, natural soil conditions cannot be readily simulated in a laboratory.

### Aeration pores

Aeration is the process where a substance gets permeated with air or another gas. The macropores in a well-drained, moist soil, usually filled with air are called aeration pores. (See also Soil porosity.)

### Aeration soil

Aeration is an exchangeable process between air from the soil and the atmosphere. In a well-aerated soil, the exchanges occur rapidly and continually.

Most crop roots, except rice, need oxygen for respiration and growth. Microbes also need oxygen for decomposition of organic matter and for oxidation of chemical compounds like ammonia, sulphur, hydrogen sulphide, iron sulphide, etc. Both roots and microbes thus consume oxygen and release carbon dioxide in the soil-air, and significantly alter its composition. Surface soils and subsoils differ in their content of oxygen, carbon dioxide and humidity.

The rate of oxygen exchange or the **oxygen diffusion rate (ODR)** depends upon the size and continuity of soil pores. Large soil pores increase the ODR, whereas small pores (like in fine clayey soils) or water filled pores restrict it. ODR depends on the soil depth, with the top few centimeters having rapid gaseous exchange as compared to the deeper layers. The wetting and drying of the soil and the soil cover also affect aeration.

A reduced aeration halts (or slows down) plant growth or the decomposition of soil organic matter. A deep ripping, drainage of excess water or addition of organic residues loosens the compacted soil and helps soil aeration.

### Aerial spraying

In aerial spraying, pesticides, fertilizers or seeds are sprayed from an aeroplane or helicopter (Fig.A.11). Aerial spraying is particularly advantageous when the ground is inaccessible, excessively wet or too large, or

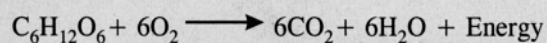


*Fig. A.11: Aerial spraying is advantageous particularly over large areas, in tree plantations or if the land is too wet. Courtesy: "The US Environmental Protection Agency" and "International Network for Environmental Compliance and Enforcement". With permission from the office of the INECE Secretariat, Washington, DC.*

when the crop height or infestation is very large. Trampling or similar techniques can reduce the need for aerial application. (See also Sprayer.)

### Aerobes

Micro-organisms requiring oxygen for respiration are called aerobes. *Rhizobium*, *Azotobacter* and *Azospirillum* are examples. In aerobic respiration, foodstuffs (usually carbohydrates) are fully oxidized to carbon dioxide and water, releasing chemical energy, as shown in the following reaction:



A fermenter or a bioreactor with an aeration system for the culture of aerobic organisms is known as **aerobic reactor**. Aerobic reactor is a piece of equipment, such as fermenter or a bio-reactor with an aeration system for the culture of aerobic organisms.

**Aerobic reactor** : See Aerobes

### Aerobic respiration

Respiration in the presence of oxygen is called aerobic respiration. Oxidation of food requires oxygen in the living cells and is accompanied by the release of water, energy and carbon dioxide.

### Aerodynamic method for evapotranspiration

Aerodynamic method, which is improved by the energy balance approach, is used for estimating evapotranspiration. The method employs meteorological formulae, which consider factors influencing the removal

of water vapor from the evaporating surface, the vertical gradient of humidity and the turbulence of airflow. Turbulence can be assessed by the vertical gradient in wind speed.

### Aeroponics

Aeroponics is a technique of growing plants, in which plants are suspended in the air and the roots are coated with nutrient solutions. The method is used to assess the effects of certain mineral elements on plant growth.

### Aerosol

Aerosol is a type of colloid. It is the dispersion of liquid or solid particles in gas such as mist, smoke or foam.

### Affinity

The tendency of an atom (or compound) to react with atoms (or compounds) of a different chemical constitution is known as its affinity.

Hydrocarbons are called paraffins (meaning, no affinity) because they exhibit no reactivity with other molecules.

The hemoglobin molecule has a much greater affinity for carbon monoxide than oxygen. The free energy decrease is a quantitative measure of chemical affinity.

### Afforestation

Afforestation is the planting of forest plant species either on a piece of land for the first time, or in denuded or degraded forests. Planting trees on a large scale (Fig. A.12 and A.13) prevents land degradation, as their roots tend to grow down to the underground water, pump



*Fig.A.12: Afforestation with Glyricidia plantation on hills.*



*Fig.A.13: Afforestation with Casuarina trees.*

the water out of the ground and transpire it into the atmosphere, thereby keeping the water cycle in balance.

Planting trees reduces (a) soil erosion because tree roots bind the soil and reduce its transportation, (b) soil salinity because trees keep the water table well below the soil surface due to transpiration of water, thus preventing salts from rising, and (c) run-off which reduces the quantity of soil particles and fertilizers being added to rivers.

Trees absorb carbon dioxide from the atmosphere during photosynthesis. Large-scale afforestation can help reduce the large amounts of carbon dioxide generated by the burning of fossil-fuel, coal and oil.

Appropriate mechanisms have been set-up all over the world for promoting afforestation, tree plantation, ecological restoration and eco-development activities. Special attention has been given to degraded forest areas and lands adjoining forest areas, national parks,

sanctuaries and other ecologically fragile areas such as the Western Himalayas and the Silent Valley in India.

### **Aflatoxins**

Aflatoxin refers to a group of highly toxic polynuclear moulds (mycotoxins.) They are designated as B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub>, G<sub>2</sub>, M<sub>1</sub> and M<sub>2</sub> and are produced chiefly by fungus *Aspergillus flavus*, which is a natural contaminant of fruits, vegetables and cereal grains. Aflatoxins are toxic to many animals including fish and birds. The B<sub>2</sub> and G<sub>1</sub> strains are carcinogens.

Aflatoxins fluoresce strongly under UV light. They are soluble in methanol, acetone and chloroform, but only slightly soluble in water and hydrocarbon solvents. Prevention of mould growth is the most effective protection against aflatoxins. Removal or inactivation is possible by physical and chemical means (solvent refining or hand picking). FDA (Food and Drug



Administration) does not allow any aflatoxin content in foods or feeds, although its presence up to 20 ppb does not attract penalty.

### AFNOR

AFNOR is a French standard system like the German DIN system or Bureau of Indian Standards (BIS). AFNOR sieves are one of the many principal sieves used in the determination of particle size of powders. In AFNOR, the length of the sides is stepped in geometrical progression with a common ratio of 1.259. (See also Sieving.)

### After crop

After crop is another crop cultivated after the harvest of a crop, on the same piece of land and in the same year.

### After cultivation

As the term indicates, after cultivation involves operations such as harrowing, rolling and other cultural activities carried out in a field after the crop is sown or planted.

### Agar

A phycocolloid derived from red algae such as *Gelidium* and *Gracilaria* is called agar. It is a polysaccharide mixture of agarose and agarpectin. (See also Agar-agar.)

### Agar-agar

Also known as **agar**, the word agar-agar is of Malaysian origin. It refers to the red seaweeds belonging to genus *Eucheuma*, used widely in Malaysia for making a gelatinous material.

Agar is a mucilage synthesized by red algae and stored along with cellulose in the cell wall. It is a dry, amorphous and gelatine-like extract, devoid of any non-nitrogenous material from *Gelidium* and other agarophytes. The extract is the sulphuric acid ester of a linear galactan, soluble in hot water but insoluble in cold water. A 1.5% agar solution can form a firm gel at around 35°C (with a melting point above 85°C), the gel being a mixture of a partially methylated neutral polysaccharide (**agarose**) and sulphuric acid ester (**agarpectin**) of a linear galactan. The gel is made under steam pressure or by boiling, and its agar content depends on the algal species, season and extraction method.

Agar is manufactured from various algae or seaweeds called **agarophytes**, whereas the term **agaroidophyte** denotes the red seaweeds that yield a substance chemically akin to an agar-like substance, but with different viscosity and gelling properties. The important agarophytes used for extraction of agar are *Acanthopeltis japonica*, *Ahnfeltia plicata* and species under the genera *Gelidium*, *Gracilaria* and *Pterocladia*. Other red algae are *Comphyllaephora*, *Eucheuma*, *Hypnea*, *Gigartina* and *Furcellaria*.

Different countries use different red algae for making agar. For example, *Suhria* (Fig.A.14), *Gelidium*, *Pterocladia*, and *Ahnfeltia* are used in South Africa, the US, New Zealand and Russia respectively. Often, the

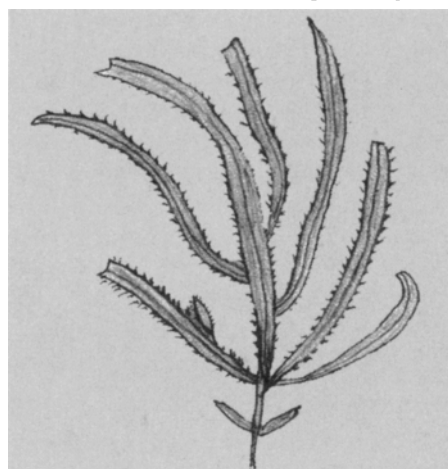


Fig.A.14: *Suhria vittata*, a red alga used in making agar.

alga carries the name of that country where it is used. For example, **Ceylon agar** (or **Ceylon moss**) refers to the dried red seaweed *Gracilaria lichenoides* found mainly in Sri Lanka, whereas the same alga found along the Indian coast bordering the Indian Ocean is called **Bengal isinglass**. *Gracilaria verrucosa* (Fig.A.15) in China is known as **Chinese moss**, whereas in Japan, agar-agar made from *Gelidium* sp. is called **Kanten**, which means cold sky, because it was made in cold winter days or high up in the mountains.



Fig.A.15: *Gracilaria verrucosa* (confervoides), an agarophyte.

Agar is used for many purposes - as a solidifying agent in the culture medium used for multiplication of beneficial bacteria like *Azotobacter* and *Azospirillum* during biofertilizer production (Fig.A.16), for algal growth, for canning tuna fish (in Japan), in the sizing of fabrics, etc. Various grades of agar are used as coating material for waterproofing paper and cloth, as a glue, as a cleaning medium for liquids, as a lubricant, in hot drawing of tungsten wire for electrical lamps (for which a suspension of powdered graphite in agar gel is used), for making photographic plates and films, for imparting

gloss and stiffness to leather, and as an adhesive in the manufacture of plywood. Agar is even used in food products, for thickening soups, sauces, ice creams, malted milks, jellies, candies and pastries. Due to its high temperature tolerance, agar is favored in food products. It substitutes pectin for making jellies, jams, marmalades, etc. and serves as a clarifying agent in the manufacture of wine, beer and coffee.



Fig.A.16: Agar-agar is used in various nutrient media as a solidifying agent. Useful micro-organisms are grown on suitable agar based media.

### Agar based inoculant

An inoculant that uses agar in its medium as a solidifying agent is called an agar based inoculant.

### Agaroidophyte

The term agaroidophyte denotes red seaweeds that yield a substance chemically akin to an agar-like substance, but with different viscosity and gelling properties.

### Agaropectin

Agaropectin is the sulphuric acid ester of a linear galactan, used for making gel.

### Agarophyte

Agarophyte is an alga or seaweed used for the manufacture of agar.

### Agarose

Agarose is a partially methylated neutral polysaccharide used for making gel.

**Aged forest:** See Forest

**Age of tree:** See Annual ring

### Agglomeration

Agglomeration or caking (synonymous with **flocculation** or **coagulation**) refers to the process of formation of large granules or a coherent mass of material from individual particles, caused by the formation of contact points among the particles. Such conversions often occur in humid atmosphere with fine powders and particulate

matter. A combination or aggregation of colloidal particles suspended in a liquid into clusters or flocks of approximately spherical shapes is also known as agglomeration. It is achieved by neutralizing electric charges which maintain the stability of colloidal suspension.

Agglomeration thus prevents the smooth and easy flow of fertilizers, thereby affecting manual application as well as application with mechanical devices. Anti-caking agents such as talc and kaoline are added to prevent agglomeration and improve flowability of fertilizers.

### Agglomeration process

The clustering or grouping together of particles is known as **agglomeration** and the process by which this takes place is known as the agglomeration process. The agglomeration process is used for the production of granular NPK products. In this process, the final mechanical strengths of the agglomerated granules are obtained by mechanical interlocking or by fitting together individual particles.

### Aggregate

An aggregate is a group of primary particles, sand, silt or clay that adhere to each other more strongly than to the surrounding particles. It is a unit of soil structure.

**Aggregate stability** can be defined as the resistance of the bonds within the aggregates to external forces of impact, shearing, abrasion or disruption arising from the escape of entrapped compressed air (slaking). It is a measure of susceptibility of the soil to water erosion, crust formation, hard setting and compaction. Stability measurements can be made on the scale of the whole soil or large aggregates ( $> 250 \mu\text{m}$ ) or on the scale of clay and silt-sized particles.

On a large scale, aggregates of whole soils are exposed to disruptive forces, usually by wet sieving and the portion of the material remaining on one or several sieves represents stable aggregates. At the scale of clay or silt-sized particles, methods generally consist of characterizing by **turbidimetry** or densitometry of the suspension, obtained by exposing the aggregate to disruptive forces.

**Aggregate stability** is determined by measuring the proportion of aggregates of a given size (usually 1 to 2 mm), which, under the influence of disruptive forces, do not break into units smaller than a pre-selected size (usually  $250 \mu\text{m}$ ).

**Aggregate stability:** See Aggregate

### Aggregation

Aggregation is a general term describing the tendency of large molecules (or colloidal particles) to combine in clusters or clumps, especially in solution. When aggregation occurs by the removal of electric charges, by the application of heat or mechanical agitation or the



addition of an appropriate electrolyte, the aggregates precipitate from the dissolved state.

### Aggregation, soil

When several soil particles are bound together they make a unit called **aggregate**, and the process of this formation is called **aggregation** (Fig.A.17). A soil consisting of strong aggregates is an aggregated soil with a stable soil structure, which is suitable for plant growth.



Fig.A.17: Aggregation of soil particles leads to the formation of clods.

### Agon

Agon is a kind of plow which opens a furrow deeper than the raise, to improve swampy terrains.

### Agricultural aircraft

For large agricultural lands, an agricultural aircraft is used to perform various operations like seeding, crop drying, fertilization, defoliation, pest control, etc. Its use is common in developed countries for large food production programs. These crafts can be helicopters or rotary wing flying machines which, due to their manoeuvrability, low-forward speed capability and operational precision offer advantages in forestry, agriculture and vector control work. However, due to the high initial price of helicopters, high adaptation and maintenance costs, and pilot skill, their use on a large scale is discouraged. An agricultural aircraft in action is shown in Fig.A.18.

Agricultural aircrafts are sought after because of their ability to operate regardless of farm conditions,



Fig.A.18: Agricultural aircraft being used for aerial spraying.

irrigational facilities and the state of crop growth. The aircraft enables agricultural operations to be carried out with great speed, but not necessarily with an energy gain or saving over other methods. The field size, proximity to human habitat and sensitive non-target cultivation, and crop plant coverage are among the factors that limit the use of these aircrafts. Some of these considerations are particularly pertinent when wet and dry type pesticides are to be dispersed.

### Agricultural biotechnology

Agricultural biotechnology is a branch of agricultural science that deals with research and application of **biotechnology** tools to agriculture. It involves techniques like genetic engineering, plant and animal tissue culture, development of bio-fertilizers and bio-pesticides, artificial synthesis of natural substances, etc. **Bt cotton** is a well known example of agricultural biotechnology.

### Agricultural chemistry

Agricultural chemistry is not a distinct discipline. It is the science of chemical compositions and alterations which occur in the production, protection and use of crops and livestock. This branch embraces life processes that are common in the creation of food and fiber for humans and animals. To assist this creation and production, many chemical substances are developed, which come under the category of herbicides, insecticides, fungicides, plant growth regulators, fertilizers, animal feed supplements, nutritional supplements and medicinal compounds for disease prevention.

Agricultural chemistry selectively embodies the elements of many disciplines that impinge on agriculture, such as genetics, physiology, microbiology, entomology, etc.

Agricultural chemistry is used to study, explore and investigate the cause and effect relationships of biochemical reactions pertinent to plant and animal growth, to develop methods to control these reactions whenever required, and to produce the desired chemical products.

### Agricultural dolomitic limestone

Agricultural dolomitic limestone is a fine, grey to white powder of a double carbonate of calcium and magnesium with 12.8% magnesium and 17% calcium. The double carbonate is much less soluble in water than the individual carbonate. (See also Calcium carbonate.)

### Agricultural engineering

Agricultural engineering is concerned with the means of continually enhancing the production of food and fiber to meet the needs of the world's rising population, and elevating the standards of living.

Agricultural engineers deal with problems involving biological materials, systems and processes. They apply physical and engineering sciences and achieve new peaks in agricultural productivity by increased mechanization.

As enhanced production is demanded from an ever-decreasing land area, agricultural engineers are constantly concerned with modifying the natural environment, to create conditions closer to the ideal for plant growth and animal production. Agricultural engineers strive to make today's livestock farm operate like a factory with a high degree of automation and mechanization, with inputs for poultry, dairy and meat animals.

Agricultural engineering involves the efficient management of soil and water resources, development of newer techniques and systems for control of soil erosion, retention of soil moisture for prevention of floods and water pollution, and supply of pure water for human use.

Agricultural engineering also relates to the development of machinery for efficient agricultural operations and post-harvest operations, such as drying of grains and forages, washing, grinding and storing of fruit and vegetables, etc.

### Agricultural fungicides

Agricultural fungicides are chemicals used in agriculture to minimize crop losses caused by phytopathogenic fungi. (See also Fungicides.)

### Agricultural lime

The **liming materials** used for correcting the acidity of soils are also called agricultural lime.

### Agricultural machinery

From initial tillage of the soil to final food and fiber production, there are many operational and precautionary steps involved. These pertain to the planting of crops, defense from pests, harvesting, conditioning, livestock feeding, and release of the farm product for processing.

To carry out agricultural operations, large special purpose machines are often used. For tillage, the generally accepted practice is to use large four, six, or eight wheel tractors or crawler tractors and high-capacity



Fig.A.19: Special purpose machines and equipments are devised for various agricultural operations. Clockwise from top left: tractor driven plow, thresher, moldboard plow and wheat and rice harvester.

plows or disks, while for loosening compacted soils, deep rippers are conveniently employed (Fig.A.19). For all this, a push-button control activates fluid power to pump through the flexible hoses to impart linear or rotating motion, as well as to perform intricate operations by highly specialized machinery. The latter can increase the precision needed in modern agriculture using, for instance, lasers for laying out irrigation systems and microprocessors for sensing or controlling such operations as regulating feed mixtures for dairy cows or grading fruits and vegetables. A variety of electronic devices are employed in the automation of many harvesters. Plows, discs, cultivators and fertilizer spreaders are mounted on tractors, but if these are too large, they are controlled and operated hydraulically.

An agricultural aircraft can perform many farming operations, such as sowing rice in flooded fields, applying fertilizers and pesticides, and spraying herbicides and insecticides on grains, vegetables and fruits.

**Agricultural meteorologists:** See Agricultural meteorology

### Agricultural meteorology

**Meteorology** deals with the atmospheric character of a region, and is concerned with the processes and phenomena of the atmosphere, especially as a means of weather forecasting.

**Agricultural meteorologists**, also called **agrometeorologists**, deal with weather prediction and its effect on crop yields, water use efficiency, weather related diseases (like pests), the length of seasons, the timing and severity of snow or frost, wind direction and intensity, problems associated with extreme weather conditions, atmospheric turbulence, remote sensing, etc.

The earth's surface exchanges radiation and mass with the atmosphere and absorbs the wind momentum; **micrometeorology** deals with the mechanisms of these exchanges.

Agricultural meteorology is concerned with the study and application of meteorology to specific problems of agriculture that arise while dealing with farming, ranching and forestry. It is also concerned with finding, in advance, the right weather conditions for the transportation of materials such as water, chemicals, fertilizers, etc.

Agricultural meteorologists use multispectral scanners placed on a number of satellites made and launched by NASA (USA), ESA (Europe), Japan, China and India for remotely sensing conditions on land and in oceans.

### Agricultural sulphur

Coarse or ground sulphur used for correcting sulphur deficiency or for increasing soil acidity is called agricultural sulphur or **agri-sulphur**. It has a sulphur content of about 90%. It is oxidized to sulphate ion by soil

micro-organisms when applied to the soil. The effectiveness of agricultural sulphur depends on its particle size, the rate, method and time of application, soil characteristics and the environment. Under some soil conditions, sulphur oxidizes slowly, and hence sulphur incorporation should be done 4 to 5 months prior to planting. Biological oxidation of sulphur in well-aerated wet soils is generally rapid.

Blending sulphur with solid N, P and K materials produces a variety of sulphur-based fertilizers. The sulphur component in sulphur-based fertilizers is also called **flowers of sulphur** or **brimstone**.

### Agricultural waste

Agricultural waste includes weeds, straw, chaff leaves, sugar cane waste, groundnut husks, etc. It is used as raw material for making compost. (See also Compost.)

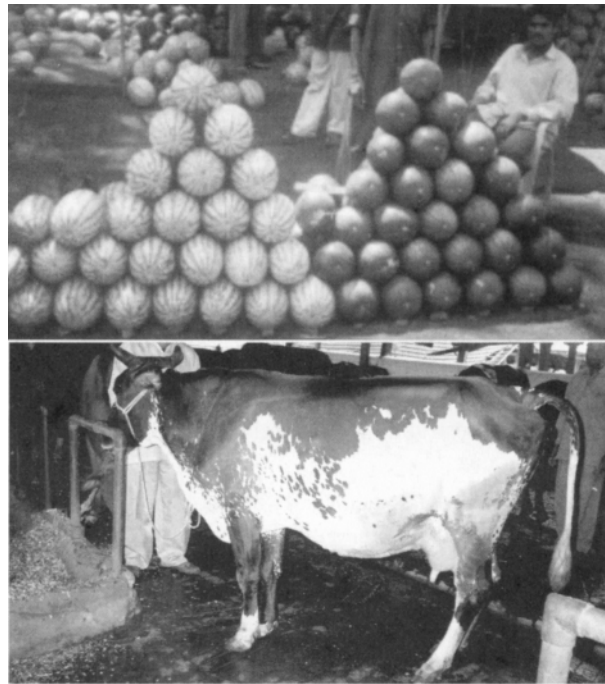
### Agricultural yield

Agricultural yield is the same as agricultural production. The yield is understood as the number of ears per unit area, the number of grains per ear and the grain size. The yield is expressed in kilograms or tons per unit area (hectare).

### Agriculture

Agriculture is essentially about the production of crops and livestock. It covers a whole range of technologies concerned with the production of useful substances from plants, animals, soils, livestock, etc., as well as related processing and marketing activities (Fig. A.20). The term agri-business includes all the technologies that are involved in the total inputs and outputs of farming.

Agriculture thus comprises the entire range of economic activities connected with the manufacture and distribution of all industrial inputs required for farming, farm products like crops and animals, conversion of these into finished products, and finally, marketing them.



*Fig. A.20: Agriculture involves activities like crop as well as livestock production, marketing, technology development, etc.*

In many countries, agriculture is the largest private sector enterprise. The final product of the food and fiber industries in the USA, for instance, amounts to about one-fourth of the gross national product and is about five times the value of farm-level production.

Agricultural practices are influenced by many factors that are characteristic of the area, the climate, soil, topography, proximity to markets, transportation, land costs and general economic standing. These vary widely across the world and bring about a wide range of agricultural products, commodity specialization, diversification as well as entrepreneurship.

As the world's population keeps increasing, there is a continuing need to develop and adopt new technologies to



*Fig. A.21: Sugar cane is an example of a monoculture crop. It provides an ideal opportunity for the survival and breeding of crop pests.*

increase food production. The last 50 years have seen many developments in agricultural science, technology and practices, which have led to an increase in the world's food production. However, advances in agricultural practices have, in several cases, adversely affected the environment. The indiscriminate use of fertilizers and pesticides has been a significant factor. The widespread practice of **crop monoculture**, in which one crop is grown over the same area year after year (Fig. A.21), has caused an increased use of pesticides, because monoculture provides an ideal opportunity for the survival and breeding of crop pests. The practice of monoculture has often led to the depletion of fertility of land and the destruction of natural habitats for useful soil flora and fauna.

Advances in agricultural technology have also stimulated the development of plowing machines with hydraulic devices that can dig deeper into the soil, and of seed drills that automatically plant seeds in the plowed soil (Fig. A.22).

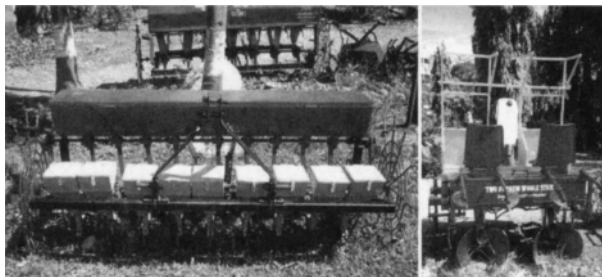


Fig. A.22: Advances in agriculture have led to the development of improved machines like multicrop planter (left) and two furrows whole stick sugar cane cutter planter.

In many developing countries, the food supply relies solely on **subsistence farming**, in which crops and livestock are also used to feed the farmer's family. In these countries, a system known as **slash and burn** cultivation is common. In this system, vegetation in the area is cut down and burned, thus returning the minerals to the soil to reuse it for crop cultivation. The practice is followed till soil fertility drops. The area is then abandoned for a number of years and another site is cultivated similarly.

Selective breeding of crop plants and farm animals has a great impact on agricultural productivity. Advanced variants of crop plants have increased the nutritional value of the produce and also increased their resistance to diseases. While animals have been selectively bred to improve their yield of milk, meat and other products, recent developments in genetic engineering have opened up new vistas to explore the use of genetically modified crops in agriculture.

**Agri-sulphur:** See Agricultural sulphur

### Agro-climatic zones

Crop yield is dependent on various factors such as weather, soil type, soil nutrient status, management practices and other available inputs. Weather plays an important role, more so in countries where drought,

flood, cold, etc. occur in a very unpredictable way. In such countries, efficient and effective crop planning can be done only after proper understanding of agro-climatic conditions. The interpretation of long-term weather parameters of each region becomes important to identify and recognize the possible cropping period.

Agro-climatic zones are the land units developed in terms of major climates that are suitable to the range of crops grown in that particular region.

India, for instance, with about 329 million hectares of geographical area, presents a large number of complex agro-climatic situations.

**Agroecosystem:** See Agroecosystem research

### Agroecosystem research

**Ecosystem** refers to a biological community of interacting organisms and their physical environment. It represents the totality of relationships among organisms and their ambient surrounding environment. All ecosystems are driven by solar energy fixed as organic carbon by green plants.

**Agroecosystem** refers to a model for working within an agricultural system with all its inputs and outputs.

Agroecosystem research encompasses a detailed examination of all elements of basic agricultural biology, in which economic production as one component of the biological response to the physical surroundings and to the inputs of materials and energy is made intelligible.

In short, agroecosystem research is concerned with the totality of the biology of an agricultural system. When production methods, brought to maturity through experiments, begin to move toward the limits of biological processes, agricultural systems become very important. During the transition, it becomes imperative to know which biological processes determine the yield and how they determine their limits. Whether or not the cycles involved in this phenomenon can sustain the high yield of intensive agricultural production (caused by chemicals) is determined by the chemistry of nutrient cycling.

Agroecosystem research uses methods of ecosystem analysis. They measure the entry of energy and material into the population of plants and animals, and explain how these inputs affect the physiological processes determining the growth and maintenance of these organisms.

The patterns of energy and material flow among plants, livestock and humans are simple, consistent and similar in most agricultural systems. Agroecosystems have relatively simple cycles.

### Agroforestry

**Agroforestry** or **farm forestry** is the cultivation of forest trees on a farm, along with conventional crops, (such as herbaceous plants) which lead to economic gains. Agro-silviculture, agro-horticulture, agro-horti-silviculture

and homestead agroforestry are examples of agroforestry systems.

Agroforestry methods have yet to be widely applied in tropical regions where scientific management techniques co-exist with traditional land use practices. At one level, shifting cultivation can be described as a form of agroforestry.

Increasingly, agroforestry involves the deliberate cultivation of woody plants (Fig. A.23) with particular qualities such as fast growth, economic value, fuel wood yield or nitrogen fixation.



Fig.A.23: Teak plantation on farm holdings, done for economic gain, is an example of agroforestry.

**Agrometeorologists:** See Agricultural meteorology

### Agronomic efficiency

Agronomic efficiency refers to the amount of biological production from relevant parts of plants under field conditions or greenhouse conditions, per unit of nutrient absorbed. Agronomic efficiency is the best way to express **nutrient use efficiency**. (See also Nutrient efficiency.)

### Agronomic nutrient efficiency

Agronomic or economic nutrient efficiency is the economic production per unit of the nutrient applied :

$$\text{Agronomic efficiency (kg/kg)} = \frac{\left[ \text{Grain yield of fertilized crop in kg} \right] - \left[ \text{Grain yield of unfertilized crop in kg} \right]}{\text{Quantity of fertilizer applied in kg}}$$

### Agronomic response, effects of particle size on

The particle size of fertilizers influences its dissolution in soil solution and its utilization by the plant. Generally, fertilizers with a low water-solubility are ground to a small size to facilitate their rapid dissolution and better utilization. For example, a raw phosphate rock ground to a particle size of about 150  $\mu\text{m}$  diameter is generally far more effective than a phosphate coarse particle.

### Agronomy

Agronomy is a branch of agricultural science which deals with the theory and practice of field crop production as well as soil and water management. It is also concerned

with the improvement and management of special purpose plants such as turf grass for lawns, recreational areas, highway embankments, drainage ditches and waterways.

Agronomy deals with the properties, uses and conservation of soils. The genesis, classification, morphology, physico-chemical and biological properties of the soil and its relationship with water are important in the consideration of soils.

The management of soils and water for efficient production of specific crops is of major interest in agronomy (Fig.A.24). An agronomic classification of plants specifies the utility of that crop, for example, grain crops, fodder crops, catch crops, etc.



Fig.A.24: Field crop cultivation, soil management and water management are major interests of agronomy.

### Agropedic horizon

Agropedic horizon is another term for **anthropic horizon**, or the cultivated horizon.

### Agro-service center

An agro-service center or a **farm service center** is a place where information is disseminated or services regarding farm inputs like seeds, fertilizers, pesticides and agricultural implements provided. Agro-service centers are generally operated by government bodies, agro industries, individual entrepreneurs, local bodies, manufacturers of fertilizers and equipments, etc.

### Agrosil colloidal silicate

Agrosil colloidal silicate is a synthetic soil conditioner that consists of partially dehydrated sodium silicate precipitated with acids, electrolytes such as phosphates or sulphates and an organic additive. The purpose of these substances is to exert biotic, chemical or physical influences on the soil, its structure, as well as the water regime. Agrosil colloidal silicate is added to soil to improve the soil structure.

### Agrostology

Agrostology is a branch of science that deals with the study of grasses, their classification, management and utilization.

### Agrotain

Agrotain is the trade name of NBPT (N-n-butyl thiophosphoric triamide), which is a urease inhibitor. It is

recommended for pre-planting surface application of urea and urea-containing fertilizers.

### Ag soil

Ag soil is a soil type with two horizons stacked one above the other, such that the black A horizon is above the G horizon. The underlying G horizon is gleyified because of a high water table underneath.

### A horizon

Horizontal layers of soil, with their own texture and color, are **soil horizons**. A horizon is one of the master soil horizons. It is the upper layer of the soil profile and generally is made up of organic matter, micro-organisms like bacteria, fungi, actinomycetes, etc., and is darkened as a result. (See also Soil horizons.)

### AI

AI is short for **aridity index**.

### Air-filled porosity

Air-filled porosity ( $F_a$ ) is a measure of the fraction of the soil bulk volume filled by air (Fig.A.25) and represents the relative air content of the soil.

$F_a$  is defined as:

$$F_a = \frac{V_a}{V_t} = \frac{V_a}{V_s + V_a + V_w}$$

where  $V_a$  is the volume of air,  $V_t$  is the total volume of soil core (comprising solid, air and water),  $V_s$  is the volume of solids, and  $V_w$  is the volume of water.

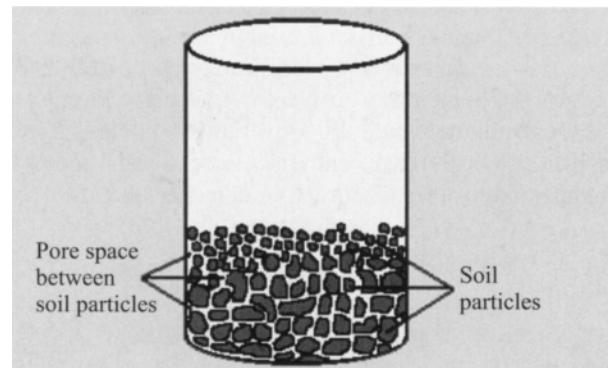


Fig.A.25: Pore spaces in soil are filled with air, when there is no water.

While reporting air-filled porosity, information on soil metric potential is relevant. Assuming that the pore space is wholly filled with water, the air-filled pore space at minus 6 kPa metric potential would be equal to the volume of macropores.

Air-filled porosity ( $F_a$ ), as a percentage of the total volume, is calculated using the tension table procedure for any specific metric potential and the following equation:

$$F_a = \frac{(W_s - W_p)}{V_t \times 0.01}$$

where  $W_s$  is the weight of the saturated soil core,  $W_p$  is the weight of the core at specific potential and  $V_t$  is the volume of the core.

The difference method (based on the soil dry bulk density,  $D_b$ , and the soil water content) is also used to determine  $F_a$  of the core at any gravimetric water content that is calculated knowing the total porosity ( $S_t$ ) from the equation:

$$S_t = 1 - (D_b/D_p)$$

where  $D_p$  is the density of the mineral soil 2.65 g/cm<sup>3</sup>.

$$F_a = S_t - \text{Water content (\%)} \times D_b$$

**Akiochi**: See Akiochi soils

### Akiochi soils

**Akiochi**, a Japanese term, describes a disease affecting rice plants wherein the crop does not attain maturity because of root damage caused by hydrogen sulphide toxicity, and/or deficiencies of (a) silicon and magnesium, (b) bases, and (c) nitrogen and potassium at later stages of plant growth.

Flooded soils contain hydrogen sulphide formed due to reduction of sulphate and anaerobic decomposition of organic matter, and are called Akiochi soils.

### Albedo

Albedo, a term describing the reflecting properties of surfaces, is the ratio of the radiant flux reflected by a surface to the incident flux. White surfaces have albedos close to one and black surfaces have albedos close to zero. For the measurement of soil moisture, neutron probes containing radioactive materials (such as beryllium or radium) are used and they work on the principle of reflection by water molecules present in the soil. Photosynthesis depends on the absorbance and reflectance of solar energy by the foliage. Surfaces of snow, water and forest have different albedos.

Two types of albedos are common. The first type is the **bond albedo** which determines the energy balance of a planet and is defined as the fraction of total incident solar energy that the planet reflects back into the space. The other type, **normal albedo**, more properly called the **normal reflectance**, is a measure of the relative brightness of a surface when viewed and illuminated vertically.

For solar system objects, bond albedos range from 0.76 for cloud-shrouded Venus to as low as 0.01 to 0.02 for some asteroids and satellites. The value for earth is 0.33. The bond albedo value depends on the spectrum of the incident radiation.

Normal reflectance, which strongly depends on the wavelength, is referred to as a '**perfectly white Lambert surface**'- a surface that absorbs no light, and scatters the incident energy isotropically. Magnesium oxide, magnesium carbonate and some other bright powders approximate this condition.



In physics, albedo represents the probability of a neutron being reflected from the same surface.

### Albic horizon

Albic horizon is a shallow mineral horizon from which clay and free iron oxides are removed, or in which iron oxides are so separated that the sand or silt particles become almost colorless.

A typical example of an albic horizon is the E horizon of podzol. It overlies a horizon of accumulation such as a spodic, argillic or natric horizon, or a fragipan, or an impermeable layer that can cause a temporary water table.

### Albite

Albite is a white or bluish-white feldspar of the plagioclase feldspar group and it belongs to the triclinic system. It has a general formula  $\text{Na}(\text{AlSi}_3\text{O}_8)$ . Albite occurs frequently as a late stage mineral associated with gem pocket, bearing lithium-rich pegmatites. The plate variety of albite is called **cleave landsite**.

Albite and **anorthite** are components in the complex plagioclase series. At high pressure, albite breaks down to jadeite ( $\text{NaAlSi}_2\text{O}_6$ ) and quartz ( $\text{SiO}_2$ ).

**Albolls:** See Mollisols

### Albumins

Albumin is a type of **protein**. Proteins, based on solubility, are classified as albumins (water-soluble), **globulins** (water-insoluble but soluble in salt solutions), and **prolamines** (soluble in alcohol-water mixtures). Albumins can be coagulated by exposure to heat.

### Aldoses

**Monosaccharides** containing an aldehyde group are called aldoses whereas those containing a ketone group are called **ketoses**.

### Alfisols

Alfisol is one of the 12 orders categorizing world soils. It consists of leached residual soils with a clay-rich B horizon. These soils are slightly-to-moderately acidic. Alfisols have umbric or ochric epipedons as well as argillic horizons and hold water at  $< 1.5$  MPa tension for at least 90 days when the soil is warm enough for plants to grow outdoors.

Alfisols develop in humid and sub-humid climates. They are distributed approximately equally across the tropical, temperate and boreal environments, and are often found under forest vegetation. They comprise 9.6% of the earth's ice-free land area. The high precipitation causes clay to move downward and form the clay accumulation horizon (Bt horizon) below. A good amount of available water facilitates plant growth during warm seasons in such soils.

Alfisols have a mean annual soil temperature of  $< 8^\circ\text{C}$  or a base saturation in the lower part of the argillic

horizon of 35% or more when measured at a pH of 8.2.

Alfisols are naturally productive soils that do not need irrigation or fertilizers. They develop under deciduous forests or savannah environments in mid-to-lower latitudes.

Alfisols can sustain traditional **slash and burn** subsistence agriculture and are moist enough to be intensively cultivable during the growing season. Relatively young soils contain weatherable primary minerals, clay minerals of 1:1 and 2:1 types and exchangeable bases. Red soils of Hyderabad and Bangalore in India are examples of alfisols.

The suborders of alfisols are aqualfs, boralfs, udalfs, ustalfs and xeralfs.

### Algae

Algae are the simplest of green plants and their study is termed **algology** or **phycology**. The population of algae varies from a few hundred to several millions per gram of soil. The main groups of algae are green algae, **blue-green algae**, yellow-green algae and diatoms. Algae form the first step in the colonization of land by plants, adding organic material and vital trace elements necessary for the growth of higher plants.

Algae are predominantly aquatic photosynthetic organisms (Fig. A.26), which transform light energy into energy-rich organic compounds. In soil, algae do not receive light but get their energy by oxidation of other materials.



Fig. A.26: Picture of a water body almost totally covered with algal growth (except as shown by the arrow).

Formerly regarded as plants, algae are now classified as members of the **kingdom Protista**. Algae are a heterogeneous group of cryptogamic plants comprising thirteen large phyla and several smaller groups, which are yet to be studied fully.

Algae are unicellular or multicellular (filamentous, ribbon-like or plate-like). The most familiar types are slimy, fibrous masses that grow in stagnant water. They tolerate a wide range of moisture conditions.

Some algae grow symbiotically with fungi, and are called lichens. **Lichens** are crucial to the early accumulation of organic matter on exposed rocks and parent materials forming the soil. Some blue-green algae fix atmospheric nitrogen and maintain nitrogen levels in soils used for paddy production.

Substances like copper sulphate are toxic to algae and serve as **algicide**. Organisms living on algae are called **algicolous**. Green algae, added to water cultures, seem to improve the growth of tobacco roots and their immunity to fungal infections.

Though algae have their own distinct morphological, cytological and reproductive properties, the basic biochemical mechanisms are very similar to other plants; all possess chlorophyll and carry out photosynthesis. Their nutrient requirements, carbohydrates, proteins and end product assimilation process are very similar to those of higher plants.

The temporary rapid growth of algae in fresh water is known as **algal boom**.

**Algal boom:** See Algae

**Algicide:** See Algae

**Algicolous :** See Algae

### Alginates

Alginates are a type of commercially exploited seaweed hydrocolloids, the other two being agars and carrageenans, which are also important hydrophilic colloids.

Alginates are considered anionic polymers of mannuronic and guluronic acids and contain carboxyl groups (in contrast with agars and carageenans which mainly have sulphate groups). Thus, alginates are similar to pectin in terrestrial plants.

**Algology :** See Algae

### Alkali

An alkali is a soluble hydroxide of a metal, particularly of one of alkali metals. The term is also applied to any substance which has an alkaline reaction. With a pH above 7, it turns red litmus blue. The alkali industry produces sodium hydroxide, sodium carbonate, salt cake, sodium bicarbonate and corresponding potassium compounds. The measurement of the concentration of alkali present is determined by titration with a standard acid using an indicator.

### Alkali feldspars

Alkali feldspars are one of the two groups of **feldspars**, which include microcline, orthoclase and sanidine. In alkali feldspars, potassium is dominant with a smaller proportion of sodium and negligible calcium. The other group of alkali feldspars is **plagioclase feldspars**.

### Alkaline soil

A soil with pH greater than 7.0 is called alkaline soil.

### Alkali soil

Soils having an exchangeable sodium percentage (ESP) higher than 15, electrical conductivity higher than 4 dS/m and pH usually above 8.5 are called alkali soils. They are also called **sodic soils** or *kallar* or *usar* soils. The toxicity, nutrient deficiency and high alkalinity of the soil (pH above 9) directly injure some plants. The high alkalinity immobilizes calcium which precipitates with atmospheric carbon dioxide to calcium carbonate. It causes toxicity of boron and deficiencies of zinc, iron and, to a lesser extent of, manganese and copper. It also affects adversely the **sorption behavior** of these elements in the soil. An excess of boron or bicarbonate in irrigation water and exposure of alkaline calcareous subsoil, when land is levelled for irrigation, worsens the situation. Indeed, most plants actually grow better or have fewer problems if the soil is moderately acidic.

Alkali soils are treated with gypsum, or with acid-forming materials like iron pyrites which release calcium from the native calcite of the soil. This is followed by leaching with good quality water. This treatment serves to replace and remove the soil exchangeable sodium beyond the root zone, thus reducing soil pH, ESP and making micronutrients more soluble for better plant absorption.

### Alkalization

Alkalization is the process by which exchangeable sodium content of the soil is increased. It results in soil compaction, through collapse of soil structure. There is also an increase in the soil pH above 8.5.

### Alkaloids

Alkaloids are basic nitrogenous organic compounds of vegetable origin containing at least one nitrogen atom in a ring structure in the molecule. Usually these are derived from nitrogen ring compounds such as pyridine, quinoline and pyrrole. Though some are liquids (they are usually colorless), crystalline solids with a bitter taste, combine with acids without water elimination. They are soluble in alcohols and insoluble in water. Some examples are atropine, morphine, nicotine, caffeine, cocaine and strychnine.

### Allantoin nitrogen

Allantoin is one of the components of ureides formula  $C_4H_6N_4O_3$ . The enzyme allantoinase present in legume nodules converts allantoin to allantoic acid. Many



tropical legumes (soybean, for instance) transport from their nodules, a large amount of their fixed atmospheric nitrogen in the form of ureides, allantoin and allantoic acid.

**Allelochemical effects, reduction of:** See Allelopathy

### Allelopathy

Allelopathy is the chemical inhibition of one plant (or organism) by another, caused by the release of substances that inhibit growth or germination. The effect manifests itself as a partial or complete inhibition of growth, or of seed germination. The donor plant releases toxic biochemical compounds to the soil, water or atmosphere, which are absorbed by the receptor plants. It occurs widely in natural plant communities and is one mechanism that causes soil degradation. Allelopathy is virtually a chemical warfare between plants. Black walnut, for instance, inhibits plant growth around its base.

Allelopathy is generally related to problems of crop production (a) on certain types of soil, (b) in stubble mulch farming, (c) with some crop rotations, (d) with crop monoculture, and (e) with forest site replanting.

Some effective allelopathic chemicals are simple phenolic acids, coumarins, terpenoids, flavonoids, alkaloids, cyanogenic glycosides and glucosinolates. Secondary compounds implicated in biochemical interactions among plants are also involved in several protective and defensive functions for the plant.

Chemicals are released into the environment by (a) oxidation of volatile chemicals from parts of the living plant, (b) leaching of water-soluble toxins from the above ground plant parts in response to rain, fog or dew, (c) exudation of water-soluble toxins from the below ground plant parts, (d) release of toxins from parts of non-living plants through leaching of toxins from the litter of sloughed root cells, or (e) microbial by-products resulting from litter decomposition. To have lasting effects on other plants, these chemicals must accumulate sufficiently in the immediate environment, or persist for some time, or be continuously released.

Allelochemicals are released as a gas or liquid from the plant roots, leaves, stems or fruits. The inhibition of one species by another is **direct allelopathy**. **Indirect allelopathy** is the inhibition of intermediate organisms (often a bacterium, alga or fungus) on which the inhibited plant depends for nutrients or water. **Auto allelopathy** is the inhibition of a species by self produced toxins.

**Allelochemical effects** can be reduced by adopting appropriate crop rotations, improving the organic matter of the soil, leaving cropped areas fallow for a period of time to allow decomposition of allelochemicals, and planting resistant cultivars or plant species.

Companion plants, which produce organic matter, or inoculation with micro-organisms that readily metabolize toxins, may be useful in perennial crop ecosystems.

Allelopathy is different from competition; the latter involves removal or reduction of vital factors like nutrient, moisture, light, space, etc. from the environment by competing species.

### Alley cropping

Alley cropping refers to a farming system in which arable crops are grown in alleys, that is, in spaces between two crops of leguminous shrubs or trees. Alley cropping hastens restoration of soil fertility and enhances productivity.

**Allocative efficiency:** See Efficiency

### Allochthonous limestone

Allochthonous limestone is one of the two sources of limestone, the other being **autochthonous limestone**. The mechanical disintegration, transportation and re-deposition of limestone from naturally existing limestone sites to a new location create allochthonous limestone, the change being usually brought about by water. This action forms clastic deposits.

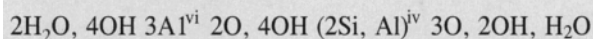
### Allogamy

Allogamy is a type of fertilization in plants. It involves transfer of pollens from the anther of a flower of one plant to the stigma of a flower of another plant. It is also called **cross-fertilization** or **cross-pollination**.

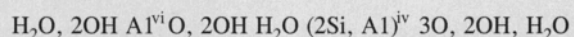
### Allophane

Allophane is a general term for amorphous, aluminosilicate gels of a wide range of composition, commonly found in volcanic soils. They have a very high phosphorus retention capacity. Most clay minerals have a layer-lattice structure, but a small group of allophanes form hollow spherical crystals.

Allophane and imogolite are most commonly found in relatively young soils (<10,000 years) formed on volcanic ash and pumice. Allophane exists as a hollow, nearly spherical particle with a diameter of 3.5 to 5 nm. An allophane with a silica to aluminum ratio of 0.5 and having a chemical formula of



contains most of its aluminum in a six fold coordination and has charge properties very similar to those of imogolite, bearing very little permanent negative charge (due to isomorphous substitution), but a variable positive and negative charge due to the proton association or dissociation at the surface hydroxyl (OH) groups. At the other extreme, an allophane with a Si:Al ratio of 1 and having a chemical formula of



contains half of its aluminum in the tetrahedral sheet and half in the octahedral sheet. Although a large layer charge arises because of the substitution of aluminum for silicon, it is neutralized to a variable extent, depending on the

ambient pH, by the association of protons at the surface OH groups. Thus, allophanes and imogolite have pH dependent surface charges at  $\text{pH} > 4.5$ .

### Alluvial soil

Soils that are created by the action of water streams or rivers in the recent past are called alluvial soils. Usually they show no horizon development. Some of the world's most fertile soils are alluvial soils. Deficiencies of nitrogen, phosphorus and zinc are common in these soils.

### Alluvium

Streams and rivers deposit sediments of various particle sizes ranging in size from small stones to big boulders. Such deposition by the action of water is called alluvium.

Some of the world's most fertile soils are derived from alluvium, and those developed in the recent past are **alluvial soils** (Fig.A.27). In Scotland, the alluvial riverside plain is called **carse** and a riverside meadow or flat land in a river valley is called **haugh**.

### Alpha alumina

Alpha alumina ( $\alpha$ -alumina) is one of two forms of white or colorless oxides of alumina. It is a stable form of aluminum oxide and is used as a catalyst or catalyst carrier. The other form is  $\gamma$ -alumina. (See also Alumina.)

### Alpha particle

An alpha ( $\alpha$ ) particle is an elementary particle consisting of two protons and two neutrons firmly bound together. The specific energy of back scattered  $\alpha$ -particles is used to analyze mineral compositions or geological formations.

An  $\alpha$ -particle is identical to the nucleus of helium ( ${}^4_2\text{He}$ ) and is either ejected by the same radioactive nuclides or arises as a product of some nuclear exchange reactions, such as (n,  $\alpha$ ) or (p,  $\alpha$ ) reactions, or by double ionization of accelerated helium atoms in an accelerator, where n and p stand for neutron and proton, respectively.

Each  $\alpha$ -particle has a mass of  $6.644 \times 10^{-27}$  kg, that is, 4.00273 a.m.u., and an electric charge of +2. The particle is highly stable and its binding energy equals 28.11 mev; its spin and magnetic moments are zero. The current of an  $\alpha$ -particle emitted from nuclei of  ${}^{235}\text{U}$ ,  ${}^{226}\text{Ra}$ ,  ${}^{232}\text{Th}$ ,  ${}^{222}\text{Rn}$ ,  ${}^{210}\text{Po}$ , etc. is called **alpha radiation**.

The range of  $\alpha$ -particles emitted depends on its energy and the absorbing medium. Owing to strong ionization and excitation effects, an  $\alpha$ -particle loses its energy very rapidly. In air, the proportionality of the range (R) of an  $\alpha$ -particle is represented by

$$R = av^3$$

where a is the constant ( $= 9.7 \times 10^{-26} \text{ m}^{-2} \text{ s}^3$ ) and v is the velocity; R is thus about 3 to 9 cm. As the stopping power of the medium correlates with the square root of its atomic mass, the range (which is in a few tens of mm for liquids and solids) of an  $\alpha$ -particle can also be calculated for other substances. Thus,  $\alpha$ -radiation is normally not hazardous to humans unless ingested directly into the body.

The high energy  $\alpha$ -particles also interact with the nuclei of an absorbing medium by Rutherford elastic scattering from atomic nuclei or by an exchange of nuclear reaction. Alternatively, the energy can be converted into Bremsstrahlung. However, the probability of such processes occurring rapidly decreases with the decreasing energy of the particles.

### Alpha radiation

A current of  $\alpha$ -particles emitted from nuclei of  ${}^{235}\text{U}$ ,  ${}^{226}\text{Ra}$ ,  ${}^{232}\text{Th}$ ,  ${}^{222}\text{Rn}$ ,  ${}^{210}\text{Po}$ , etc. is called alpha radiation.

### Altered peat

A peat where organic matter is decomposed beyond recognition is called altered peat.

### Alternate farming

A crop rotation system that includes a ley is known as alternate farming or **ley farming**.



Fig.A.27: Alluvial soil, which is the most fertile soil, is largely deposited along river banks due to floods or the flow of water.

### Alternate furrow irrigation

Alternate furrow irrigation involves irrigating alternate furrows in a field. This method is ideal in areas of acute water scarcity where production of normal yields is a must. Alternate furrow irrigation allows more rapid coverage of the field during an irrigation period and requires less labor. It also leaves the soil dry enough to absorb water during the rains, and reduces run-off and erosion. The time interval between the two sessions of irrigation must, however, be short.

### Alternate host

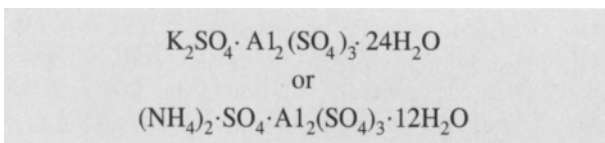
An alternate host, also known as the **secondary host**, is the host plant of a pathogen (usually a fungus). It is called so because the pathogen completes a part of its life cycle on this host. For example, species of *Berberis* and *Mahonia* plants serve as alternate hosts for *Puccinia graminis tritici*, the fungal pathogen, causing the black stem rust disease of wheat.

### Alternative agriculture

Generally farming involves use of chemical fertilizers, pesticides, etc. with a view to obtaining a higher yield. Alternative agriculture or alternative farming mainly relies on the use of organic manures, biological agents, recycled waste material, etc., bypassing the use of chemicals and fertilizers. A common example of alternative agriculture or alternative farming is **organic farming**.

### Alum

Alum is a double sulphate of a monovalent and trivalent salt. It is represented as:



Alum acts as a flocculating agent. It is used in sewage treatment and in purification of drinking water. Alum is also used in the preparation of mordant and as a fireproofing agent.

Aluminum sulphate is sometimes erroneously called alum in some industries (such as in the paper industry).

### Alumina

Alumina is a white or colorless oxide occurring in two forms,  $\alpha$ -alumina and  $\gamma$ -alumina. The  $\gamma$ -alumina turns into a stable  $\alpha$  form on heating. Naturally occurring alumina is called **corundum** or **emery**.

The gemstones ruby and sapphire are aluminum oxides colored by minute traces of chromium and cobalt, respectively. The highly protective film of oxide formed on the surface of aluminum is yet another structural variation, a defective form of rock salt.

Pure aluminum oxide is obtained by dissolving bauxite ore in sodium hydroxide solution to eliminate

insoluble impurities. Seeding the solution with material from a previous batch precipitates the hydrated oxide, which on further heating gives  $\gamma$ -alumina at 500 to 800°C and pure  $\alpha$ -alumina at 1150 to 1200°C. The latter is one of the hardest materials known. It is used widely as an abrasive substance in both its natural and synthetic forms. Its refractory nature makes alumina bricks an ideal material for furnace linings and high temperature cements.

Alumina occurs in phosphate rocks along with iron and other impurities in small percentages. Alumina and iron in phosphate rock make the superphosphate moist and sticky. The maximum acceptable alumina and iron in the rock for farming is 3 to 4%.

### Aluminum

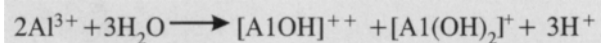
Aluminum, the third most abundant element in the earth's crust, is a silvery-white lustrous metal belonging to Group 13 of the Periodic Table (Fig.A.28). The metal is highly reactive and is protected by a thick transparent oxide layer that gets formed quickly in air. Aluminum and its oxides are amphoteric.

Fig.A.28: Position of aluminum, a beneficial element, in the Periodic Table.

Pure aluminum, which exists in a large number of alloys, is extracted from purified bauxite by electrolysis. Its lightness, strength (when alloyed), corrosion resistance and electrical conductivity make aluminum suitable for a variety of uses, including in the construction of vehicles, aircrafts, buildings and overhead power cables.

Aluminum (Al) is an important soil constituent. It is toxic to most plants at a soil pH below 6.0.

Aluminum ion forms octahedral coordination with water molecules and hydroxyl ions. If soil is not strongly acidic, one (or more) of the water molecules ionizes, releasing the hydrogen ion (H<sup>+</sup>) into the solution and increasing the soil acidity.



The toxic level of soluble and exchangeable aluminum can be substantially reduced by first raising the soil pH in the range of 5.2 to 5.5 and by further liming to make it in the range of 6.0 to 6.5.

In acidic soils, aluminum may compete for uptake with copper and make the soil copper deficient. Molybdenum is adsorbed strongly by oxides of aluminum and iron, thereby making the molybdenum unavailable to plants. Increasing aluminum in the soil

solution also restricts the uptake of calcium and magnesium by plants.

Aluminum ions are toxic to the roots of many plants such as cotton, tomato, alfalfa, celery, barley, corn, sorghum, and sugar beets. Aluminum toxicity is probably the most important growth limiting factor in many acid soils.

The symptoms of aluminum toxicity caused by excess soluble aluminum are not easily recognize in crop plants. White-yellow interveinal blotches form on leaves causing them to dry out and die. Aluminum toxicity also reduces the growth of both shoots and roots.

An excess of aluminum interferes with cell division in plant roots, inhibits nodule initiation (by fixing the soil phosphorus to forms that are less available to plant roots), and decreases root respiration. Aluminum interferes with enzymes controlling the deposition of polysaccharides in cell walls and increases cell wall rigidity by cross-linking with pectins. It reduces the uptake, transport, and use of nutrients and water by the plant.

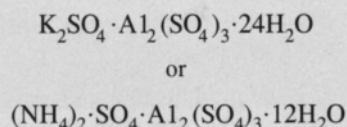
Aluminum-injured roots are characteristically stubby and brittle. The root tips and lateral roots thicken and turn brown. The root system as a whole, appears coralline, with many stubby lateral roots but no fine branching.

The toxicity problem of aluminum is not economically correctable with conventional liming practices. A genetic approach has the potential to solve the problem of aluminum toxicity in acid soils.

### Aluminum sulphate

Aluminum sulphate is a white or colorless crystalline compound. The hydrated variety of aluminum sulphate has 18 water molecules,  $[Al_2(SO_4)_3 \cdot 18H_2O]$  and occurs naturally as a rare mineral **alunogenite**. Aluminum sulphate, which is prepared by dissolving aluminum hydroxide or china clay (aluminum silicates) in sulphuric acid, decomposes on heating to sulphur dioxide, sulphur trioxide and aluminum oxides. The aluminum ions present in aluminum sulphate hydrolyze in water and produce hydrogen ions. Hence, the solution becomes acidic. Anhydrous aluminum sulphate, like its hydrated form, is soluble in water but insoluble in ethanol.

Aluminum sulphate acts as a flocculating agent and is very important in sewage treatment and purification of drinking water. It is also used in the preparation of mordants and as a fireproofing agent. In the paper industry, it is sometimes erroneously called **alum** which is a double sulphate of a monovalent and trivalent salt described as:



When applied to soils, aluminum sulphate dissolves and decomposes to sulphuric acid. It is used to acidify neutral or alkaline soils.

Aluminum sulphate is popular with floriculturists in the production of azaleas, carnations and other acid tolerant ornamental plants.

Plants can develop aluminum toxicity, when aluminum sulphate is used indiscriminately.

### Alunogenite

Alunogenite is a naturally occurring form of hydrated aluminum sulphate  $Al_2(SO_4)_3 \cdot 18H_2O$ .

### AM

AM is a substituted pyrimidine (2-amino-4-chloro-6-methyl pyridine) that acts as a nitrification inhibitor. It controls nitrogen loss by inhibiting the nitrification process in soil and helps the effective utilization of fertilizer nitrogen. This action by AM inhibits the growth of *Nitrosomonas* and retards conversion of  $NH_4^+$  to  $NO_3$  for several months. Another effective compound used for the same purpose is **N-serve** [2-chloro-6 (trichloromethyl) pyridine], also known as **nitrapyrin**.

AM, as an inhibitor, loses its activity because of volatilization, leaching and also warm temperatures. (See also Nitrification inhibitors.)

### Amargosite

Amargosite is another name for **bentonite**. It is a soft, porous, light-colored rock consisting largely of colloidal silica. It is composed chiefly of clay minerals of the montmorillonite group which swell extensively when wet.

### Ameliorant

Ameliorant is a substance added to soil to improve its physical and/or chemical properties, thereby increasing crop yield. For example, the addition of lime to acidic soils or the addition of gypsum to sodic soils improves crop yields. The process of addition of ameliorants to the soil is **amelioration**. Amelioration by tillage, liming, manuring, etc. increases land value.

**Amelioration:** See Ameliorant

### Amendment

Amendment is a material added to reclaim abnormal soils like acidic or saline-sodic soils. It involves a part (or most) of the exchangeable sodium in saline-sodic soils (which is harmful to plants and which disperses clay particles) being replaced by more favorable calcium ions in the root zone. The addition of lime to acidic soils for crop production is an example of an amendment. Thus, amendment is a substance added to the soil to improve its physical and chemical properties for better farming.

### Amensalism

Some organisms produce a substance which is inhibitory to other organisms. The inhibitory effect of such a substance is called amensalism (similar to allelopathy.) For example, the fungus *Penicillium* inhibits bacteria.



Autotrophic organisms, principally green plants, synthesize amino acids. The simplest naturally occurring amino acid is glycine ( $\text{H}_2\text{NCH}_2\text{COOH}$ ). About 20 commonly occurring amino acids have been identified as building blocks of most plant and animal proteins.

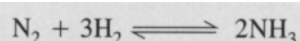
Amino acids are linked by peptide bonds formed between the carboxyl group of the first amino acid and the amino group of the second amino acid. Many such amino acid molecules join together to form peptide linkages and hence the polypeptide. The sequence of these amino acids in the polypeptide determines the shape and structure of proteins and their properties and biological role.

### Amino urea

Amino urea is another name for **guanidine**. It is an analogue of urea and is made by reacting urea with ammonia under pressure or by heating calcium cyanamide with ammonium iodide.

### Ammonia

Anhydrous ammonia is the basic building block of almost all nitrogen fertilizer materials. Most of the world's ammonia is produced synthetically by a direct reaction of the elements by the **Haber-Bosch process**. The process involves an exothermic and reversible reaction that proceeds with a concurrent decrease in volume.



There are certain conditions for the above reaction to proceed optimally. These are: (a) temperature of  $500^\circ\text{C}$ , (b) pressure of 270 to 350 atmospheres, (c) a catalyst containing finely divided iron with molybdenum or calcium as a promoter, finely divided osmium or uranium, finely divided nickel over pumice stone or ferric oxide with traces of silica and potassium oxide, and (d) pure gases (as otherwise the catalyst gets poisoned).

Free ammonia is extremely toxic to micro-organisms, animals and higher plants. Ammonia produced as a part of normal metabolism is immediately converted into a less harmful substance like urea and is excreted in urine. Ammonia can readily penetrate cell membranes whereas the ammonium ion is impermeable. There is a close relationship between the pH and the concentration of the free ammonium ( $\text{NH}_4^+$ ) ion. The capacity of soil to retain ammonia increases with increasing soil moisture and clay content.

Ammonia is the least expensive and most widely used nitrogen fertilizer. It is used in the manufacture of other fertilizers like urea, ammonium sulphate and ammonium chloride.

Ammonia is also used in the manufacture of nitric acid, hydrazine hydrate, urethane, acrylonitrile and sodium carbonate (**Solvay process**). In addition, ammonia is used as a refrigerant, in nitriding of steels, in the petroleum industry, in the manufacture of explosives and rocket fuel, as a yeast nutrient, etc.

Anhydrous ammonia, which has great affinity for water, contains approximately 82% nitrogen. This is the highest nitrogen content that any nitrogen fertilizer can have. As anhydrous ammonia is a gas at atmospheric pressure, to avoid its loss to the atmosphere during application, ammonia is injected at least 7 to 20 cm below the soil.

The simplest nitrogen solution is aqua ammonia which contains 25 to 29% ammonia by weight. Since ammonia volatilizes above  $10^\circ\text{C}$ , aqua ammonia is injected into the soil to a depth of 5 to 10 cm.

**Ammonia, anhydrous:** See Anhydrous ammonia

### Ammoniacal fertilizer

An ammoniacal fertilizer contains nitrogen in its ammoniacal ( $\text{NH}_4^+$ ) form. Chemical (or synthetic) fertilizers are the most important sources of nitrogen. Anhydrous ammonia, for instance, is the building block for most chemically derived nitrogen fertilizer materials.

For convenience, nitrogen compounds are grouped into three categories, namely the ammoniacal, the nitrate and the slow release fertilizers. This classification is based on their availability to plants.

The major ammoniacal nitrogen fertilizers are urea, aqua ammonia, anhydrous ammonia, ammonium nitrate, ammonium chloride, etc.

Table-A.2 shows the composition of some common ammoniacal nitrogen fertilizers.

Table-A.2: Composition of some common ammoniacal nitrogen fertilizers

Fertilizer	% N	% $\text{P}_2\text{O}_5$	% S
Anhydrous Ammonia	82	-	-
Aqua ammonia	20-24	-	-
Ammonium nitrate	33-34	-	-
Ammonium sulphate	21	-	24
Ammonium nitrate sulphate	30	-	5-7
Urea	45-46	-	-
Urea sulphate	30-40	-	6-11
Urea sulphur	30-40	-	10-20
Urea ammonium nitrate solution	28-32	-	-

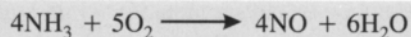
### Ammonia liquor

Ammonia liquor is another name for **aqua ammonia** or **ammonia solution**. It is made by absorbing ammonia in water, and its commercial grades generally contain about 80% ammonia.

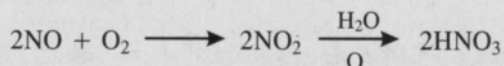
### Ammonia oxidation

When heated electrically to around  $750$  to  $900^\circ\text{C}$  in the presence of a platinum or platinum rhodium gauze catalyst, ammonia gets oxidized by atmospheric air.





This reaction is exothermic and the heat generated maintains the catalyst temperature. The nitric oxide (NO) formed is further oxidized to nitrogen dioxide (NO<sub>2</sub>) by atmospheric air, and the cooled gas (50°C) is absorbed in water in the presence of air to give nitric acid.



The efficiency of ammonia conversion, expressed as the percentage of ammonia converted into nitric oxide, depends strictly on the catalyst activity, selected temperature, pressure, mixing efficiency of the incoming air with ammonia, and the velocity of the gas flowing through the catalyst. Among the non-platinum catalysts are the oxides of cobalt, iron or chromium.

Nitric acid made as above is of 98% purity and has a specific gravity of 1.50.

Owing to the absorption of ammonia, the ammonium ion produced in the soil is oxidized to nitrite by the bacterium *Nitrosomonas* and then to nitrate by *Nitrobacter*. This oxidation by micro-organisms is called **nitrification**. The process is rapid unless the soil is strongly acidic, cold or wet.

**Ammonia production by coal gasification:** See Ammonia production processes

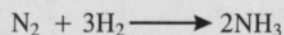
**Ammonia production, other process techniques for:** See Ammonia production processes

### Ammonia production processes

Synthetic ammonia is the principal source of all nitrogen fertilizers. Almost all commercial fertilizer nitrogen is supplied by or is derived from ammonia.

Ammonia is either directly applied to the soil or is applied as an aqueous solution with other nitrogenous fertilizers like ammonium nitrate or urea.

The process of synthesizing ammonia was developed by Fritz Haber in collaboration with Carl Bosch, and has come to be known as the **Haber-Bosch process**. It is based on the catalytic reaction of hydrogen with nitrogen at a high temperature and pressure.



Nitrogen is taken from the air. Hydrogen is derived either directly or as a by-product. The raw materials required for hydrogen manufacture are water, natural gas, fuel oil or petroleum fractions, coal and coke oven gas.

More than 60% of the hydrogen is derived from methane or natural gas, fuel oil or petroleum fractions by steam reforming and partial oxidation. Coal gasification was a source of hydrogen until World War II.

In the commercial production of ammonia, the selection of feed stock is the most important factor in determining the capital investment and production costs.

The availability and cost of raw materials are also among factors to be taken into account while deciding on the construction of a new plant for the production of hydrogen (Table-A.3.)

Table-A.3: Feedstock versus process/technique for hydrogen products.

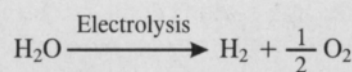
Feedstock	Process/technique to produce H <sub>2</sub>
Water	Electrolysis
Natural gas/ Associated gas	Partial oxidation/steam reforming
Naphtha	Steam reforming/partial oxidation
Fuel oil / LSHS (Low Sulphur Heavy Stock)	Partial oxidation
Coal	Partial oxidation
Coke oven gas	Reforming /partial oxidation / low temperature separation

The major feedstock in the production of hydrogen includes water, natural gas, naphtha and heavy residual coke gas or coal. The major steps include electrolysis, partial oxidation or gasification, desulphurization, primary reforming, secondary reforming, shifts in high and low temperature, carbon monoxide and carbon dioxide removal, methanation, compression and ammonia synthesis. The various methods of getting pure hydrogen for ammonia synthesis are briefly discussed below:

(i) **Electrolysis:** Hydrogen is obtained from water by alkaline or acid electrolysis. Several ammonia plants have been built to produce ammonia from hydrogen derived from the electrolysis of water. These plants are located where power is available at a low cost, such as Norway, Egypt, Zimbabwe, Peru, Iceland and Canada.

Purified water mixed with potassium hydroxide (added to increase the conductivity) is electrolyzed in electrolytic cells. These cells in an alkaline medium vary in their efficiency in producing hydrogen. But the power consumed is around 4.3 kWh/m<sup>3</sup> of hydrogen. The process generates one volume of oxygen per two volumes of hydrogen or about 0.7 ton of oxygen per ton of ammonia produced. The other byproduct is heavy water, as pure water contains 0.0135% heavy water (D<sub>2</sub>O). Heavy water is used in nuclear reactors.

The cost of producing ammonia by the electrolytic hydrogen process is not as dependent on the size of the plant, as it is on the cost of electricity. It is much simpler to produce ammonia by electrolytic hydrogen than by processes involving other feedstock.

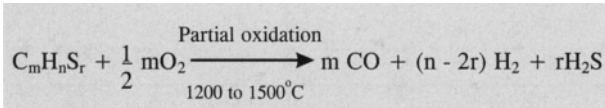


Hydrogen is also a byproduct of the electrolytic production of chlorine from caustic soda. Such feedstock is used by several small ammonia plants. The amount of hydrogen produced is too small to supply normal plants.

(ii) **Partial oxidation process:** Hydrogen is produced from hydrocarbons by partial oxidation at high

temperatures. In this process, hydrocarbons that are heavier than naphtha can be used as feedstocks for ammonia production. Natural gas and naphtha can also be used. The plant cost for partial oxidation process is considerably higher than that for steam reforming. However, the partial oxidation process offers a wider choice of feedstock with greater tolerance for impurities. The feedstock requirement is typically about 0.76 tons of heavy oil per ton of ammonia.

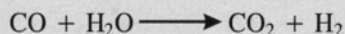
Among the main partial oxidation processes are those named after **Texaco**, **Shell** and **Koppers-Totzek**. Partial oxidation is carried out at 1200 to 1500°C without a catalyst. The complex chemical reactions involved are represented by:



After the side reactions arising from hydrocracking, steam gasification, reforming and water gas shift, the typical composition of the resulting gas is 46% H<sub>2</sub>, 47% CO and 4% CO<sub>2</sub> (on dry basis) with small amounts of H<sub>2</sub>S and nitrogen. A considerable amount of soot (carbon) remains suspended in the gas.

The Koppers-Totzek process is also used for coal. The Shell and Texaco processes are similar. The Shell gasifier operates at 3.5 to 6 MPa pressure and the Texaco gasifier operates at up to 9 MPa pressure. The gasification pressure in partial oxidation processes has been gradually increased in the range of 60 to 90 atmospheres, which helps to save energy for compression. The problems that limit the operating pressure of the gasification process are (a) the loss of mechanical strength of the Fe/Cr oxide catalyst used for high temperature shift, at 6.0 MPa, and (b) the compression of oxygen required for gasification. Safety is a great concern because the reactivity of oxygen increases with pressure. A new catalyst, developed by BASF, uses Co/Mo sulphides which overcome the mechanical strength losses at high steam partial pressure.

There are more than 48 ammonia plants based on the Texaco partial oxidation technology. The raw gas is freed of the carbon formed during gasification, by scrubbing with water. The raw gases after desulphurization are sent to shift conversion, where carbon monoxide is converted into carbon dioxide and hydrogen through steam.



Ammonia production using air (instead of oxygen) for partial oxidation or gasification has been commercialized by Texaco. The air gasification concept can be applied to a complete range of feedstock materials from natural gas and refinery gas, through liquid hydrocarbons, to coal and coke. The excess nitrogen from ammonia synthesis gas is recovered by cryogenic condensation.

(iii) Coal gasification: Until World War II, coal-based ammonia production predominated the industry. Later, it gave way to other processes when cheap natural gas and steam-reforming processes became available.

About 10% of the world's ammonia production is based on coal, coke or lignite. Coal gasification process for ammonia production can be classified according to the method of gasification used – fixed-bed (**Lurgi**), fluidized bed (**Winkler**) or entrained bed (**Koppers-Totzek** and **Texaco**.) The so-called 'fixed' bed is more accurately a 'moving' bed gasification. Coal lumps (5 to 30 mm) charged at the top descend against the upward gas stream. These get dried, pre-heated, carbonized and finally gasified by the oxygen and steam entering from the bottom. Coal ash is discharged at the bottom through a grate, as slag. This method requires less oxygen and less heat compared to other methods. Also, it avoids the grinding and drying of the coal. The Lurgi method operates at 3 MPa pressure.

The limitations of the fixed or moving bed gasification method are that (a) the coal has to be in the form of lumps (5 to 30 mm), (b) the coal has to be of a non-caking variety or must be heated to prevent caking, and (c) the by-product formed (tar, phenolic compounds, light oils, etc.) must be removed or disposed of. Incidentally, the fine coal particles formed during the preparation of the sized coal feed are burned in an auxiliary plant to generate steam.

In the fluidized bed gasification process (Winkler), coal is ground to a particle size 15 mm or less and introduced into the fluidized bed through feed screws. Steam and oxygen are injected near the bottom of the fluidized bed. The latter is isothermal (1000°C) in contrast to the gradual temperature increase of coal in the moving bed process. Hence, there is no tar or liquid product and the gas contains only hydrogen and carbon monoxide with less than 1% methane. Large amounts of gas are entrained in the gas stream. The process produces 6 to 12% carbon containing char, which is removed from the bottom. The two advantages of the Winkler gasifier are that it works with almost any grade of coal or lignite and is adaptable to high capacity units. However, the process produces ammonia at low pressures (1 to 3 atm), thus adding to costs. The final gas needs electrostatic precipitator for cleaning up.

Most of the present coal-based ammonia plants use the Koppers-Totzek process. This is essentially a partial oxidation process (like most coal gasification processes) and is adaptable to heavy oil, light hydrocarbons or natural gas. In this process, coal is dried and ground to pass through a 200 mesh sieve. The powdered coal is picked up by streams of oxygen and blown into the gasification chamber. Steam enters through annular openings around the burners. The gasification is complete in about one-tenth of a second at temperatures in the range of 1000 to 1200°C. Part of the ash produced is fused and removed from the bottom and another part is entrained in the gas. The gas contains about 56% CO, 31% H<sub>2</sub>, 11% CO<sub>2</sub> and less than 0.1% CH<sub>4</sub>. The ash is removed by wet scrubbing and electrostatic precipitation. The remainder of the ammonia synthesis gas preparation is similar to that under partial oxidation of fuel oil.

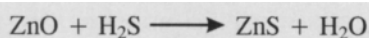
The disadvantages of the process are that it requires coal to be finely ground, and it involves operation at low pressures (1 to 3 atm) and high oxygen consumption.



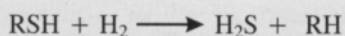
The Texaco process differs from the Koppers-Totzek process in that the finely ground coal is slurried with water (35 to 40% water). The preheated slurry is fed along with oxygen into a gasifier that can operate at up to 80 atm and a temperature of around 1300°C. The fused ash, quenched with water, is removed from the bottom as a slurry. The hot gas is cooled and the soot and fly ash are removed by scrubbing. The sequence of the remaining steps of synthesis gas preparation is the shift conversion of carbon monoxide, and the removal of hydrogen sulphide and carbon dioxide by the wash of cold methanol and liquid nitrogen. The principal effluents from the process are coal slag, waste water, hydrogen sulphide, carbon dioxide, a mixture of carbon monoxide and nitrogen from nitrogen wash, and small quantities of tail gas from ammonia synthesis.

(iv) **Steam reforming:** Steam reforming is carried out in two stages, using primary and secondary reformers. In primary reforming, natural gas feed is converted to hydrogen and carbon monoxide, by the feed's reaction with steam. In secondary reforming, the reaction continues and air is introduced to assure the required amount of nitrogen for ammonia synthesis. The feedstocks need purification before being subjected to reforming.

Natural gas is purified by removing carbon dioxide and hydrogen sulphide. Depending on the source, natural gas may contain entrained dust or droplets of oil or water, which are to be removed by separators, filters, etc. After initial purification, natural gas is compressed to reformer pressure and passed over activated carbon at ambient temperature or over hot zinc oxide (290 to 400°C) to remove sulphur by absorption. In some cases, both activated carbon or zinc oxide (ZnO) treatments are used.

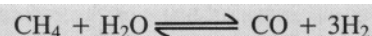


Chlorides, present in some natural gases, poison the low temperature shift catalysts and are removed by absorbents. If the feedstock contains non-reactive sulphur, hydro treating is carried out. The preheated gas or vaporized naphtha is mixed with hydrogen (recycled synthesis gas) and passed through a "hydrotreater" containing a cobalt-molybdenum catalyst. This catalyst converts sulphur compounds into hydrogen sulphide (H<sub>2</sub>S.) The gas then goes to a sulphur removing catalyst, like zinc oxide.

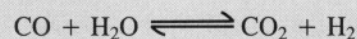


Sulphur, chlorides and other catalyst poisons can enter the ammonia plant in the steam or in the air, to the secondary reformer. Precautions need to be taken to avoid this. One method is to keep the sulphur content in natural gas below 0.5 ppm. The main sulphur compounds in natural gas are hydrogen sulphide and mercaptans. In addition, a layer of guard absorbent may be placed on top of the catalyst, particularly in the case of a low temperature catalyst.

The primary reforming step is to convert the bulk of the hydrocarbon feed to hydrogen and carbon monoxide by the reaction of steam.



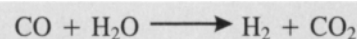
Nickel is used as a catalyst. A shift conversion also occurs to some extent.



The methane-water reaction is endothermic and requires a large amount of heat. Promoters such as potassium may be added to increase the strength of the base composition, its durability and porosity.

The gas that leaves the primary reformer usually contains 5 to 15% methane on dry weight basis. The secondary reforming process aims at conversion of methane to hydrogen, carbon monoxide and carbon dioxide and the supply of required nitrogen for ammonia synthesis. Reforming is done by adding air in the amount required to give an N:H atomic ratio of 1:3 in the synthesis gas. The oxygen in the air burns part of H<sub>2</sub>, CO and CH<sub>4</sub>, thereby raising the temperature high enough for rapid completion of the reforming process. When air is the source of nitrogen to the secondary reformer, heat is supplied from that generated in combustion reactions together with the heat in the preheated air and in the gas from the primary reformer. The gas leaving the secondary reformer contains around 56% hydrogen, 12% carbon monoxide, 8% carbon dioxide, 23% nitrogen, and less than 0.5% methane and argon. It also contains steam from nearly half of the total volume of gases on dry weight basis.

Carbon monoxide conversion to carbon dioxide is carried out in two steps. They are (a) a high-temperature conversion, and (b) a low-temperature shift conversion. Potassium carbonate with various additives is used to promote the absorption of carbon dioxide in most ammonia plants. The carbon monoxide from the secondary reformer is cooled to around 375°C which is the optimum temperature for the shift conversion reaction.

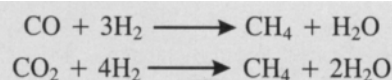


Carbon monoxide is converted into carbon dioxide and hydrogen, by passing over an iron oxide with a small amount of chromium oxide catalyst bed in the presence of steam. This exothermic reaction is carried out in two steps with heat removal between the steps as the reaction is more rapid at high temperatures (300 to 400°C) and equilibrium is more favorable at low temperatures (200 to 275°C.) Most of the low temperature shift catalyst contains zinc and alumina in addition to copper.

After shift conversion of carbon monoxide to carbon dioxide, the gas may contain 18% carbon dioxide. From the year 1940 to 1960, a 20% solution of mono ethanolamine was used to absorb carbon dioxide. Since 1960, most plants have started to use potassium carbonate solution with additives that promote absorption and inhibit conversion. These improved processes are known as the **Catacarb process** and the **Benfield process**. The major advantage of potassium carbonate solution is the lower heat requirement for stripping carbon dioxide from the solvent. A modified process known as **Vetrocoke process**, which uses a mixture of potassium

carbonate and sodium carbonate with arsenic oxide, is more efficient. This process absorbs carbon dioxide in the plant more efficiently but results in the emission of relatively large amounts of CO<sub>2</sub> to the atmosphere, thereby causing pollution. An increased carbon dioxide concentration in the atmosphere contributes most to greenhouse effect and acid rain. Special care should be taken in the Vetrocoke process because it uses potassium carbonate solution activated by arsenic oxide (As<sub>2</sub>O<sub>3</sub>) as an absorbent. Careless operation of such plants can lead to contamination of the soil and underground water sources.

The gas after carbon dioxide absorption contains about 0.3% carbon monoxide and less than 0.1% carbon dioxide. These gases must be removed prior to the ammonia synthesis step by methanation, lest they decrease the activity of the ammonia synthesis catalyst and cause deposition of ammonium carbonate in the synthesis loop. These methanation reactions are reverse of the reformer reactions. And a nickel based catalyst is used where hot gases are passed over the catalyst at a temperature of 300 to 350°C.



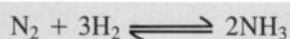
These reactions are exothermic. The synthesis gas after methanation contains about 74% hydrogen, 24% nitrogen, 0.8% methane and 0.3% argon, on a dry weight basis. This gas is to be compressed to pressure ranging from 10 to 80 MPa depending on the ammonia synthesis process.

Reciprocating compressors, which were once in general use, are still used for small plants (less than 500 tons per day). However now, centrifugal compressors driven by steam turbines, are used in most new plants.

Because reciprocating compressors are driven by electric motors, they are more efficient (~87% efficiency) than the centrifugal compressors (~70% efficiency), but are more expensive and their maintenance costs are also higher.

**Ammonia synthesis:** The synthesis gas calls for the removal of water before the gases enter the synthesis converter because of the adverse effect of water on the catalyst. Most modern plants use molecular sieve dryers to remove water in the synthesis gas to less than 1 ppmv. The sieves are usually located at the inter-stage of the synthesis gas compressor.

The purified synthesis gas mixture containing hydrogen and nitrogen in the ratio of 3:1 reacts at a temperature of the order of 500°C and a pressure of 270 to 350 atmospheres over an activated iron oxide catalyst.



The catalyst is mainly ferroso-ferric oxide (Fe<sub>3</sub>O<sub>4</sub>), promoted using potash, aluminum, calcium or magnesium. The catalyst also could be poisoned by sulphur, arsenic, phosphorus, chlorine and heavy hydrocarbons.

A typical ammonia synthesis reactor is a steel cylinder of a height of 10 to 18 m and a diameter of 80 to 140 cm. Ammonia synthesis converters differ, depending on the type of flow – whether axial, radial or cross. The converters also differ in the way temperature control of the reactants is achieved, and on how low reaction heat recovery is done. Though initially, quench converters were popular, indirect-cooled converters are currently used where heat exchangers are used to cool the gas. Catalyst efficiency is improved by increasing the surface area per unit volume with a small particle size. A radial flow converter provides a larger gas flow area compared to the axial flow converter. All modern, low-energy designs of ammonia converters use radial or cross flow designs with indirect temperature control.

The conversion of synthesis gas is incomplete in a single pass, but a large amount of ammonia is produced by its removal from the gas stream and by recycling the unreacted synthesis gas. The gas that leaves the converter contains around 12 to 18% ammonia, depending on the pressure. The conversion per pass increases with pressure. This gas is cooled, first by heat exchange with the incoming gas, and then by air or water. The cooled ammonia gas is finally condensed to a liquid form by refrigeration. The degree of cooling required depends on the pressure of the ammonia gas. At high pressures, most of the ammonia can be condensed by water cooling. At low pressures (15 to 20 MPa), refrigeration is essential for condensation. For atmospheric storage, the gas needs to be cooled to minus 33°C. The gas remaining after ammonia condensation is recycled to the converter by using a compressor.

Ammonia manufacture consumes intense energy for such major operations as compression of air, synthesis gas, refrigeration, etc. The relative energy consumption per ton of ammonia produced, assuming the consumption with natural gas as the feedstock is as follows:

Natural gas	1.0
Naphtha	1.1
Fuel oil	1.15
Coal	1.45

The manufacture of one ton of ammonia requires about 980 NM<sup>3</sup> of natural gas, one ton of naphtha or fuel oil or 3.8 tons of coal. Against a thermodynamic requirement of energy to get one ton of ammonia (4.46 million Kcals), the energy consumption by the steam reforming process is 9.6 million Kcals. Technology is being developed to reduce the overall energy inputs for ammonia synthesis. The various issues being addressed include recovering lost heat, bringing down synthesis pressure (with an improved catalyst) and impurities in the synthesis gas, reduce pressure drops by better converter designs, and the use of improved purification methods and better design of cold exchange or heat exchange equipment. It is now possible to produce ammonia with an input energy of 8 million Kcals/ton of ammonia produced.

Production of ammonia by the steam-reforming process is relatively clean and presents no problem to the environment. In ammonia manufacturing plants, several

hazardous substances (toxic, flammable, explosive) get handled at a wide range of temperatures and relatively high pressures. Pre-emptive environmental protection measures should be taken, like with plant design, the construction material used and plant operation.

**Other process techniques:** The present day low-energy designs for ammonia production use indirectly cooled converters. The design and layout of various plants available differ considerably. The major plant technologies used today are based on the **Kellogg's horizontal converter** and **Topsoe series 200 converter**. These gas-based plants use two catalyst layers with an intermediate heat exchanger for the feed, all in a single vessel.

**Kellogg technology** uses a horizontal cylindrical converter in which catalyst beds are arranged along side each other. The gas flows vertically through rectangular beds. The catalyst beds and the interchanger are mounted on a trolley system, which can be inserted into the vessel.

The **Topsoe series 200 converter** is a radial flow converter. It has two catalyst beds with annular cross sections. The gas flows radially inwards. A heat exchanger is installed at the first beds outlet. The gas enters at the bottom and flows through an annular space between the shell and the catalyst bed. This annular flow of gas keeps the temperature low and prevents the attack of hydrogen of the shell. The gas is heated in the interchanger before it enters the first catalyst bed. The effluent gas from the first bed is cooled in the interchanger and it flows through the second bed. The ammonia axial-radial converter permits part of the gas to flow axially through the catalyst and the remainder radially through the catalyst bed. This converter design can be retrofitted into old converters.

**Uhde technology** uses three catalyst beds. The first two beds and an interchanger are housed in one vessel. High pressure steam generated by a waste heat boiler cools the gas before it enters the catalyst bed placed in another vessel. The effluent from the third bed goes through a high pressure steam boiler.

To control the concentration of inerts in the recycle gas, it is necessary to draw a purge stream from the synthesis loop. The purge gas has the composition of 61% hydrogen, 20% nitrogen, 13% methane, 4% argon and 2% ammonia. Recovering and recycling hydrogen from this purge gas can reduce the quantity of hydrogen to be produced by steam reforming. The cryogenic process, the membrane separation process and the pressure swing adsorption processes have been commercially used in ammonia plants for the recovery of hydrogen. Hydrogen recovery of 90 to 98% can be achieved in the cryogenic process while membrane separation process gives a recovery of 85 to 90% hydrogen. Hydrogen recovery of 70 to 80% is achieved in the pressure swing adsorption process.

In 1988 ICI set up two identical 450 tons per day ammonia plants based on the **Leading Concept Ammonia (LCA) process** in Britain. The LCA process is different from the traditional steam reforming process.

The LCA concept has a 'core' unit consisting of key process operations and a separate utility area containing power and steam systems, refrigeration, carbon dioxide recovery and other utilities. Natural gas is desulphurized and passed through a feed gas saturator where it comes in contact with circulating hot process condensate. The ammonia synthesis reactor operates at a pressure of 8.0 MPa using a cobalt-promoted catalyst. The gas enters at 225°C and leaves at 380°C.

The **Linde Ammonia Concept** is a combination of a hydrogen plant, nitrogen plant and an ammonia synthesis loop. The hydrogen plant uses a primary reformer, shift converters and a pressure swing adsorption unit to get ultra pure hydrogen. Pure nitrogen from an air separation plant is mixed with pure hydrogen to give inerts-free ammonia synthesis gas. The process has the following three features that differentiate it from the conventional steam-reforming process: (i) Elimination of secondary reforming. (ii) The use of an isothermal shift reactor for carbon monoxide shift conversion. (iii) A pressure swing adsorption unit to remove carbon dioxide, methane and small residual amounts of carbon monoxide from the hydrogen stream producing 99.999 mole percent pure hydrogen.

The advantages of the Linde Ammonia Concept are as follows. (i) The isothermal shift reactor allows conversion to 0.7% carbon monoxide on dry basis in a single step. (ii) The catalyst bed is kept at a constant temperature of about 250°C by a spiral wound cooling coil. (iii) The isothermal reactor technology has been in use at many places worldwide. The pressure swing adsorption unit is able to supply pure hydrogen even in the case of a disturbance upstream in the reformer. This is in contrast to the conventional plant where disturbances in the carbon monoxide shift or carbon dioxide removal areas cause a shutdown due to high temperature in the methanator.

The **PARC process** combines air separation (to produce nitrogen) with steam reforming, HT shift and pressure swing adsorption (PSA) to make synthesis gas. In the proprietary PSA unit, nitrogen purge is used to enhance hydrogen recovery and to fulfill the stoichiometric nitrogen requirement. A Rankine cycle is used to generate electric power from the heat of the high temperature shift converter. This process eliminates the need for secondary reforming, LT shift, carbon dioxide scrubbing and methanation. If carbon dioxide is required for urea manufacture, a carbon dioxide scrubbing unit is added in front of the PSA unit. The overall energy efficiency ranges from 7.0 to 7.6 Gcal/ton of ammonia, depending on plant specification.

The **Topsoe economic process** uses optimized units of the ammonia process rather than radically new schemes. The test runs of this process have shown the production of about 7Gcal/ton of ammonia produced. Further improvement in the pre-reformer, positioned upstream of the primary reformer allows reformer feed to be heated to a higher temperature at a low steam: carbon ratio without deposition of carbon. In addition, Topsoe

has developed a shift conversion catalyst based on copper, which does not promote a Fischer-Tropsch reaction at a low steam dry gas ratio.

New developments are related to two steps of ammonia synthesis: (a) construction of the reactor, and (b) development of a new catalyst. While developing a new catalyst, favorable properties of ruthenium as an ammonia synthesis catalyst are important.

The major differences between the two catalysts (the conventional iron based and ruthenium based catalyst) are that the ruthenium based catalyst (a) is required in a much lower volume, and (b) operates at a lower pressure and at a higher temperature. Lower mole percent of hydrogen and nitrogen and a high partial pressure of ammonia are allowed in the process. The expected immediate energy saving is about 0.2 to 0.3 Gcal/ton of ammonia. The stability of this new ruthenium catalyst must be proven before it replaces the iron based catalyst. Until now, two carriers have been experimented. These are: a special graphite by Kellogg and a ceramic support by Topsoe.

**Kellogg Advanced Ammonia Process (KAAP)** is based on a precious metal-based ammonia synthesis catalyst, jointly developed by M.W. Kellogg and British Petroleum. This new catalyst, which uses ruthenium supported on a proprietary graphite structure with various co-promoters, was seen to provide 10 to 20 times the activity of a conventional iron-based catalyst. The KAAP ammonia plant has the following technical features: (a) a single-case synthesis gas compressor, (b) a radial flow, intercooled converter design, (c) a low-pressure synthesis loop, and (d) a high activity ammonia synthesis catalyst.

The KAAP reactor is a four-bed, intercooled, radial flow, hot wall vessel. The first bed uses a charge of conventional magnetite catalyst to take advantage of the high ammonia reaction rate at a low ammonia concentration. The other three beds are charged with the new catalyst. A series of intercoolers and external steam generators are provided for heat integration. The feed to the KAAP reactor contains 15% ammonia which is increased to more than 21% at the exit of the reactor.

The advantages of the KAAP technology compared to those of the current low-energy technology are the following: (i) The synloop energy consumption is reduced by 40%, which when translated to the overall plant energy reduction is about 1.0 GJ/ton. (ii) The overall plant capital cost is reduced by about 5%.

The **Topsoe S-250 converter system** also uses two radial flow converters in series with waste-heat boilers between the converters and after the last converter. This system saves energy to an extent of 0.11 Gcal/ton of ammonia over the previous Topsoe converter S-200.

This new converter has (a) a low pressure because of the radial flow, (b) use of small particle size catalyst, (c) high conversion per pass due to indirect cooling, and (d) good operability and easy temperature control. The new converter system offers either the same performance

with a smaller catalyst volume or higher conversion by full use of the third bed.

Ammonia production is highly capital intensive. Its investment costs greatly depend, among other things, on the bidding location and on the relative strength of international currencies, and also on the market for construction of chemical plants. The processes have been standardized for ammonia production by steam reforming of natural gas, naphtha and other hydrocarbons in plants using centrifugal compressors. Standard designs for 900, 1040, 1360 and 1500 tons per day (tpd) have evolved. The majority of new plants are in the range of 1000 to 1500 tpd capacity.

There are relatively fewer plants to produce ammonia by partial oxidation of heavy oil or coal. The basic elements of the cost of production of ammonia using four different starting materials are as follows:

Feedstock	Plant cost factor
Natural gas	1.00
Naphtha	1.15
Heavy oil	1.60
Coal	2.00

In practice, plants from 100 to 600 tpy (tons per year) of ammonia production capacity are considered small scale plants. While ammonia production is a mature technology, there is room for improvements in its efficiency and reliability by making use of (a) optimization of pre-reforming and adiabatic reforming processes, (b) new methods in electrically driven compressors (like three dimensional impellers), (c) better design of furnace elements (burner nozzles, insulation) and heat exchangers, (d) improved steam generation methods, (e) integrated gas turbine drives with steam turbines, (f) more efficient process condensate stripping to produce medium-pressure steam, (g) improved ruthenium catalyst and its alternatives, (h) easier and economically viable dynamic control systems, and (i) reduced emissions of carbon dioxide and oxides of nitrogen to meet stringent environmental regulations.

**Storage and transportation:** Most ammonia is shipped from the plants where it is produced to other locations for direct use as fertilizer or for further processing into finished fertilizers, or for use as a raw material for non-fertilizer products. Ammonia is mostly transported by sea. Ships that carry it also carry other liquefied gases, such as liquefied petroleum gases (LPG). Ammonia is almost invariably transported in the liquid state and, therefore, it must either be compressed or refrigerated, semi-refrigerated or pressurized. Fully refrigerated storage tanks are equipped to maintain the temperature at about minus 33°C. In semi-refrigerated storage tanks, ammonia is kept at a moderately low temperature of 0 to 5°C at which the pressure is about 400 to 500 kPa. Unrefrigerated pressure storage tanks usually are designed for pressures of up to about 1.8 MPa, which should be adequate for any ambient temperature normally encountered in most climates.

Transportation of anhydrous ammonia by pipelines is economically attractive in some cases. Examples of long distance ammonia transportation by pipelines are found, for instance, in the United States, Russia and Mexico. Anhydrous ammonia is also transported by rail and road.

### Ammonia solution

The solution of ammonia in water is called ammonia solution, commonly referred to as **aqua ammonia**. It is also called aqueous ammonia, **ammonia liquor** or **ammonium hydroxide**. It is the simplest nitrogen solution made by forcing compressed  $\text{NH}_3$  (anhydrous ammonia) gas into water.

### Ammonia-sulphur solution

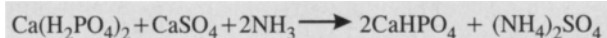
Ammonia-sulphur solution is made from anhydrous ammonia and sulphur. The typical commercial solutions are temperature dependent and contain 74.2% nitrogen and 10% sulphur.

### Ammoniated sulphate

Ammoniated sulphate, also called **ammonium dihydrogen phosphate sulphate**, is a double salt of  $\text{NH}_4(\text{H}_2\text{PO}_4)$  and  $(\text{NH}_4)_2\text{SO}_4$ . It is made by neutralizing a mixture of  $\text{H}_2\text{SO}_4$  and  $\text{H}_3\text{PO}_4$  by gaseous ammonia.

### Ammoniated superphosphate

Ammoniated superphosphate is a powdered or granulated grey material with an acid odor. Anhydrous or aqueous ammonia is mixed with ordinary superphosphate obtained by treating phosphate rock with sulphuric acid:



To 9.1 kg of phosphorus (in the form of  $\text{P}_2\text{O}_5$ ), 2.7 to 3.2 kg of ammonia is added. Where concentrated superphosphate is used, 2 kg of ammonia is added for every 9.1 kg of phosphorus.

Ammoniated superphosphate contains 2 to 6% nitrogen and 6 to 21% phosphorus (14 to 49%  $\text{P}_2\text{O}_5$ ). Ammoniation of superphosphate offers an inexpensive way of adding nitrogen to a fertilizer, which reduces the water-soluble phosphorus content to less than 20% in ordinary superphosphate whereas nearly 50% in triple superphosphate. Nitrogen promotes phosphorus uptake by plants by (a) increasing the tip and root growth, (b) altering the plant metabolism and (c) increasing the solubility and availability of phosphorus. Ammoniacal fertilizers facilitate absorption of phosphorus better than nitrate fertilizers do.

Ammonium superphosphate becomes easy to store when made free-flowing by mixing with non-caking agents like limestone, sand, rice hull, granite dust, kaolin clay or tobacco stems. It is not effective as a fertilizer for wheat and rice in laterite soil, but gives higher response in black cotton soil, alluvial and calcareous soils.

Similar to ammonium phosphate sulphate, ammoniated superphosphate forms an acid in the soil. In

humid regions, soils develop acidity as a result of leaching, erosion and crop removal. This feature is being used successfully even in low fertility agricultural soils.

### Ammoniating solution

Ammoniating solution is ammonia or a solution of ammonium nitrate or urea in **ammonia liquor**. It is used for ammoniating superphosphate or its derivatives. (See also Nitrogen solution.)

### Ammoniation

Ammoniation is the process of introducing ammonia (ammonia liquor or aqua ammonia) into fertilizer materials like superphosphate to form ammoniated compounds, such as ammonium polyphosphate and ammoniated superphosphate. Various products are formed depending on the (a) proportion of ammonia used, (b) resulting reaction temperatures, (c) time of standing and (d) other components in the mixture. Ammonia first reacts with the free acid present in the superphosphate and mono-calcium phosphate forming other compounds.

### Ammonia volatilization

When ammonium ion is in a basic solution, ammonia volatilization leads to a loss of nitrogen from soil or water to the atmosphere in the form of ammonia gas. The amount of ammonia lost is proportional to the quantity of ammonium ion ( $\text{NH}_4^+$ ) and ammonia in the soil solution and the soil pH. The losses are highest from the surface when ammonium fertilizers or urea are applied on calcareous (high carbonate content) soils. On non-fertilized soils, the ammonia losses are smaller (< 10%) compared to as much as 30% when urea or ammonium fertilizers are applied.

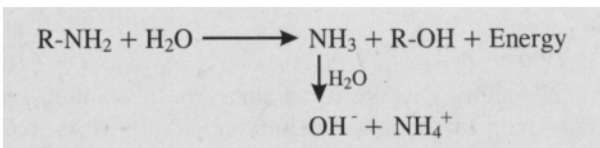
To minimize the loss by volatilization, the applied fertilizer should be covered by a layer of soil or washed with water. The loss can be reduced by inhibiting the urease enzyme activity by adding urease inhibitors (like phenols, quinones, various insecticides and substituted urea.)

Generally, ammonia volatilization in calcareous soils is greater with urea fertilizers than with ammonium salts; the exception is of ammonium sulphate or diammonium phosphate that forms an insoluble calcium salt as a precipitate. Ammonia losses increase with moisture and with the increased application of fertilizers, compared to those by dry nitrogen sources. The volatilization is greater with broadcast application on a wet surface soil compared to subsurface and surface band methods.

**Ammonification** is the conversion of organic nitrogen to its ammonium form in the presence of bacteria like *Bacillus*, *Proteus* and other heterotrophs. This conversion is termed **mineralization**. The rate of ammonification is faster if the soil is warm, well aerated and moist.

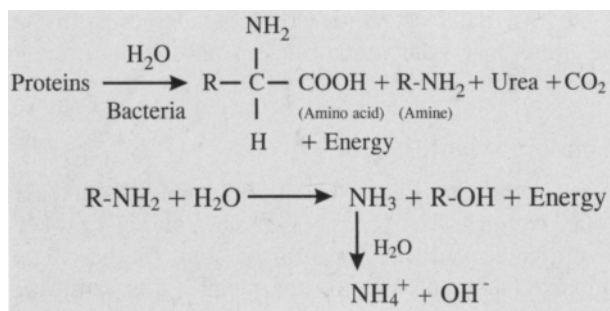
In ammonification, the amines and amino acids, produced by the aminization of organic compounds (like

protein) are decomposed by heterotrophs to release ammonium. This step is called **ammonification** and is represented as follows:



### Ammonification

Ammonification is a biological process by which organic forms of soil nitrogen are converted into ammonia or ammonium ions. The final reaction in this process is the hydrolysis of amino groups. The amines and amino acids released in aminization are reacted upon by other heterotrophs, releasing nitrogen in an inorganic ammonium ( $\text{NH}_4^+$ ) form. Both aerobic and anaerobic micro-organisms can carry out this reaction. A diverse population of bacteria, fungi and actinomyces is capable of releasing ammonium ions.



The released ammonium ion may be (a) nitrified, (b) utilized by plants, (c) lost by **ammonia volatilization**, (d) adsorbed on complex clay materials, (e) fixed in the crystal lattices of 2:1 expanding clay minerals, or (f) immobilized by soil micro-organisms. The rates of ammonia release are more rapid in aerobic than in anaerobic environment. (See also Ammonia volatilization; Nitrification.)

### Ammonium bicarbonate

Ammonium bicarbonate, also called **ammonium hydrogen carbonate** ( $\text{NH}_4\text{HCO}_3$ ), is a low nitrogen containing fertilizer (17%N), used largely in China. It is produced by heating ammonium hydroxide with excess carbon dioxide and evaporating the water formed.

Ammonium bicarbonate is a hygroscopic, white, crystalline compound soluble in water but insoluble in alcohol and acetone. It decomposes above  $35^\circ\text{C}$  to ammonia, carbon dioxide and water vapor, releasing irritant fumes. Only 30% of the applied nitrogen of this fertilizer is recovered by plants owing to the unstable nature of ammonium bicarbonate.

### Ammonium bisulphite

Ammonium bisulphite is a solution grade fertilizer, available commercially as a 55 to 60% solution. It is made by absorbing sulphur dioxide (obtained as a by-product from smelting operations) in aqueous ammonia solution. This non-pressurized solution provides both

sulphur and nitrogen. It has a salt-out temperature of  $0^\circ\text{C}$ .

Ammonium bisulphite is compatible with liquid fertilizers, such as aqueous ammonia and polyphosphate solutions, and can be stored in containers made of steel, aluminum or plastic.

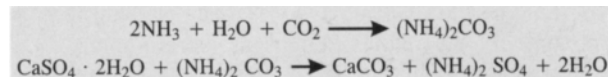
### Ammonium carbonate

Ammonium carbonate,  $(\text{NH}_4)_2\text{CO}_3$ , is an intermediate product formed during the synthesis of urea. Ammonium carbonate on decomposition yields urea and water.

### Ammonium-carbonate-gypsum process for producing ammonium sulphate

The production process involves the reaction of ammonium carbonate with gypsum, removing the precipitated calcium carbonate by filtration, evaporation and crystallizing ammonium sulphate followed by centrifuging the liquor.

This method, also known as the **Merseburg Process**, is based on combining ammonia and carbon dioxide to first produce ammonium carbonate, which is then reacted with gypsum or anhydrite to yield ammonium sulphate and calcium carbonate in an exothermic reaction:



The exothermic process has many advantages, such as the availability of a byproduct (calcium carbonate) used in cement production and agriculture. This process does not require any sulphur supply. The major disadvantage is the large energy (steam) requirement for ammonium sulphate recovery from the dilute solution.

At the Sindri plant in India, ammonia is absorbed in water and carbonated at a pressure of about  $2.1 \text{ kg/cm}^2$  in a series of two aluminum towers. The prepared liquor strength corresponds to approximately 170 g of ammonia and 225 g of carbon dioxide per liter. In FACT (The Fertilizers and Chemicals Travancore Ltd.), Travancore, India, jet absorbers are used for preparing ammonia solution and ammonium carbonate liquor in conjunction with a carbonating tower.

Natural gypsum or anhydrite, when used, is ground so that about 90% of the material passes through a 120 mesh sieve. When gypsum, as a byproduct of phosphoric acid plants is used, impurities are removed by repulping the filter cake prior to washing and dewatering on a drum or disc filter.

Reactions of ammonium carbonate and gypsum solutions are carried out in a series of wooden vessels or mild steel vessels having steam coils and agitators to give a total retention time of 4 to 6 hours. The slurry produced is filtered and the calcium carbonate cake washed and dewatered. The solution is evaporated and the crystals are centrifuged and dried in a rotary drier at  $120^\circ\text{C}$ .

### Ammonium chloride

Ammonium chloride, like all other ammonium salts, is used as a fertilizer. It contains 24 to 26% nitrogen and is



available as white crystals or granules. A coarse form of this fertilizer is preferred to the powdered form for direct application. Its crystals are used in compound fertilizers.

Ammonium chloride is a good source of nitrogen for cotton, rice, wheat, barley, maize, sorghum, sugar cane and fiber crops. It is easy to handle. In some cases, however, the material tends to become lumpy and difficult to spread.

Ammonium chloride is used either directly for fertilization or in a variety of compound fertilizers, such as ammonium phosphate chloride or ammonium potassium chloride or in combination with urea or ammonium sulphate.

As a fertilizer, ammonium chloride has an advantage in that it contains 26% nitrogen, which is higher than that found in ammonium sulphate (20.5%). In terms of per unit cost of nitrogen, ammonium chloride is relatively cheaper than ammonium sulphate and has some agronomic advantages for rice. **Nitrification** of ammonium chloride is less rapid than that of urea or ammonium sulphate. Therefore, nitrogen losses are lower and yields, higher.

However, ammonium chloride is a highly acid forming fertilizer and the amount of calcium carbonate required to neutralize the acidity is more than the fertilizer itself. Further, it has a lower nitrogen content and a higher chloride content compared to urea and ammonium nitrate, making it harmful to some plants.

Several methods are used to produce ammonium chloride. The most important is the **dual-salt process (modified Solvay process)** wherein ammonium chloride and sodium carbonate are produced simultaneously using common salt and anhydrous ammonia as the principal starting materials. When ammonium chloride is mixed with phosphatic and potassic fertilizers, a large amount of soil calcium is lost as its conversion into soluble calcium chloride causes it to leach out easily.

Like ammonium sulphate, ammonium chloride can be applied to wet land crops. In terms of the agronomic suitability, it is generally rated as equal to other straight nitrogenous fertilizers.

Ammonium chloride is, however, not ideal for grapes, chilies, potatoes and tobacco as the added chlorine affects the quality and storability of these crops.

Industrial uses of ammonium chloride are in dry-battery manufacture and as a flux for soldering and brazing.

### Ammonium chloride production processes

Ammonium chloride is used as a fertilizer either as such or in combination with other fertilizers.

Manufacturing methods for producing ammonium chloride are (a) the dual-salt processes, whereby ammonium chloride and sodium carbonate are produced simultaneously, (b) direct neutralization of ammonia with hydrochloric acid, and (c) miscellaneous methods.

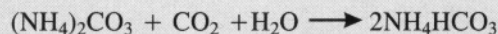
(a) Most of the ammonium chloride for fertilizer use

is made by the **dual-salt process**. In this process, ammonium chloride is salted out by the addition of solid, washed sodium chloride rather than by decomposition by lime to recover ammonia. This is the **modified Solvay process**.

In the original **Solvay process**, an ammoniacal solution of 30% sodium chloride is treated with carbon dioxide in large absorption towers to form ammonium carbonate:



Additional carbonation produces ammonium bicarbonate:



The addition of sodium chloride gives sodium bicarbonate and ammonium chloride:



The sodium bicarbonate centrifuged or filtered from the ammonium chloride solution is calcined to produce sodium carbonate and carbon dioxide, which is recycled.

In the Solvay process, equilibrium is reached at about 75% completion, and the mother liquor is reacted with lime to give ammonia:



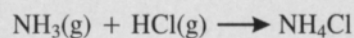
The calcium chloride formed can be sold or discarded, depending on the market.

In the modified Solvay process, the mother liquor, after the removal of sodium bicarbonate, is ammoniated, cooled below 15°C and salted out using washed solid sodium chloride. The precipitated ammonium chloride is centrifuged, washed and dried. The fine crystals can be granulated by roll compaction. Large ammonium chloride crystals of 2 to 3 mm size have been developed by cooling, nucleation and crystallization, under closely controlled conditions in specially designed vessels.

The slurry from the crystallizer is centrifuged, washed and dried to about 0.25% free moisture in a rotary drier at 105°C. After the removal of ammonium chloride, the liquor is reammoniated to start a new cycle of operations.

As the demand for soda ash is comparatively lower than that for nitrogen fertilizers, ammonium chloride from this source is not likely to meet the nitrogen fertilizer needs.

(b) **Direct neutralization method:** High purity ammonium chloride is made by anhydrous ammonia vapor directly reacting with hydrochloric acid gas:



This neutralization reaction is carried out under reduced pressure in rubber lined steel vessels. Concentrated hydrogen chloride gas is passed through an aspirator where it is diluted to about 20% concentration. Ammonia is admitted through another sparger or by tangential nozzles in the base of the reaction vessel. Air agitation is employed. A reduced pressure of 250 to 300



mm of mercury and a slurry temperature of 75 to 80°C are the typical operating conditions.

Operation under vacuum provides cooling and elimination of abnoxious acid vapors, in addition to attendant costs and maintenance charges. The acid and ammonia feeds are adjusted to achieve a steady pH of 8. The control system cuts off the acid when the pH falls below 7 to protect the rubber and plastic lined reactors and centrifuges from corroding. The slurry containing 80% solid ammonium chloride is withdrawn and separated by centrifuging. In some cases, drying is done by blowing hot air through the crystals before discharge. Alternatively, a top-feed filter-drier can be used instead of the centrifuge.

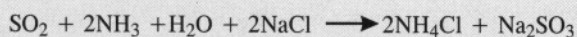
The mother liquor from the centrifuges is pumped back to a saturator. The gases evolved from the liquor are scrubbed to prevent corrosion. The liquor from the condenser-scrubber system is returned to the mother liquor tank. In the direct reaction between hydrochloric acid and ammonia, traces of chlorine can cause explosions by the formation of nitrogen trichloride, warranting adequate safety precautions.

Anti-caking agents such as certain fatty acid derivatives or inert powders, when added to the crystallizer or sprayed on the crystals, reduce caking tendencies on storage. Granulation by roll compaction provides material for direct application.

(c) **Miscellaneous processes:** Ammonium chloride can also be made by reacting ammonium sulphate with sodium chloride:



In another process, which is quite expensive and used only for producing small quantities of ammonium chloride, sulphur dioxide or sulphite liquor reacts with ammonia and sodium chloride:



Ammonium chloride is formed in NPK fertilizers by the action of potassium chloride with ammonium nitrate or sulphate, as per the following reaction:



These reactions go to completion in most granulation processes involving these NPK fertilizers.

Ammonium chloride containing 24 to 26% nitrogen can be either crystalline or granular. Coarse crystals or granular materials are used for direct application and fine crystals are used for making compound fertilizers.

### Ammonium citrate

Ammonium citrate is a white, granular, water-soluble salt of ammonia and citric acid. It is used in a neutral solution for determining the phosphorus content of phosphate fertilizers (such as calcium hydrogen phosphate (CaHPO<sub>4</sub>)), that are insoluble in water but dissolve in complexing citrate solutions.

The fertilizer residue, after extraction of water-soluble phosphorus, is re-extracted with a neutral or strongly alkaline solution of 1 normal (1N) ammonium citrate for a prescribed period, and the slurry filtered. Citrate-soluble phosphorus is the phosphorus content in the filtrate and is expressed as a percentage by weight of the fertilizer.

The extraction of phosphate with 1N ammonium citrate is carried out routinely for 30 minutes, first at room temperature and then at 40°C. For neutral ammonium citrate solution, a temperature of 65°C is preferred.

Some European countries use an alkaline ammonium citrate solution, which extracts smaller amounts of phosphorus. Some experts consider it to be better correlated with phosphorus uptake and plant growth. However, most countries use a neutral normal ammonium citrate solution for extracting citrate soluble phosphorus.

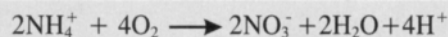
**Ammonium dihydrogen phosphate sulphate:** See Ammoniated sulphate

### Ammonium fertilizers

Ammonium sulphate, ammonium nitrate, ammonium phosphate, ammonium chloride, anhydrous ammonia and ammonia solution are among the important ammoniacal fertilizers. These nitrogenous fertilizers are combinations of ammonium and other elements with anions like nitrate, chloride, sulphate, phosphate, etc., which are water-soluble and easily assimilated by plants.

The ammonium part has to be nitrified (for conversion into its nitrate form) for plant absorption in the early stage of growth. Only paddy can absorb ammonium as such to meet its nitrogen needs. The ammonium ion is readily adsorbed on the colloidal complex of the soil and gets fixed and resistant to leaching.

Ammonium fertilizers render soils acidic as microbes oxidize ammonium cations to nitrate anions. These fertilizers require to be applied in combination with neutralizing calcium carbonate:



The amount of lime needed depends on the acidity of the fertilizer anions (Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>) and on how much ammonium is oxidized.

Table-A.4 gives the theoretical acidity values (lime requirement) of some ammonium fertilizers.

Table-A.4: Acidity (lime requirement) of some ammonium fertilizers (theoretical)

Fertilizer	Lime requirement kg/kg N
Ammonium chloride NH <sub>4</sub> Cl	5.30
Ammonium nitrate NH <sub>4</sub> NO <sub>3</sub>	1.80
Ammonium sulphate (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	5.35
Calcium ammonium nitrate CaNH <sub>4</sub> (NO <sub>3</sub> ) <sub>3</sub>	0

## Ammonium fixation

Ammonium fixation or the **fixation of ammonium ion** is a phenomenon by which certain clays (illites, montmorillonites, etc.) bond ammonium ions tightly between the mineral lattices that are neither exchangeable for other ions nor available to plants. However, near the edges of the clay lattice, external ions may replace some of the ammonium ions if clays are expanded, and such nitrogen may become available for plant growth. The number of ammonium ions fixed on the edges of the clay lattices increases as more ammonium is added. The ammonium ions fixed are less than the adsorbed quantities of ammonium. The clay fixation of ammonium ion ( $\text{NH}_4^+$ ) provides some protection against rapid nitrification (followed by leaching.) The important fractions in fixing ammonium ions are coarse clay (0.2 to 2  $\mu\text{m}$ ) and fine silt (2 to 5  $\mu\text{m}$ ).

The moisture content, soil temperature and presence of other ions like potassium affect the fixation of ammonium ions. Generally, freezing and drying increase ammonium fixation. The presence of potassium ions restricts the fixation of ammonium ions as potassium fills the fixation sites. For this reason, adding potassium fertilizers, before the application of ammonium or ammonia-producing fertilizers, reduces ammonium fixation.

## Ammonium form, immobilization of

Immobilization is the use or reuse of soluble nitrogen ( $\text{NH}_4^+$  and  $\text{NO}_3^-$ ) by plants or microbes. Most of the soil nitrogen added as a fertilizer, is immobilized into organic materials, (mostly as protein), in higher plants or microbes.

## Ammonium hydrogen carbonate

Ammonium hydrogen carbonate is another name for **ammonium bicarbonate** ( $\text{NH}_4\text{HCO}_3$ ). It is a low nitrogen containing fertilizer (17% N), used largely in China. It is produced by heating ammonium hydroxide with excess carbon dioxide, followed by evaporation of water. (See also Ammonium bicarbonate.)

## Ammonium hydroxide

Ammonium hydroxide is also known as **ammonia solution**, **aqua ammonia**, **aqueous ammonia** or **ammonia liquor**. It is the solution of ammonia in water and is commonly referred to as ammonium hydroxide. It is the simplest nitrogen solution made by forcing compressed ammonia (anhydrous ammonia) gas into water.

## Ammonium metaphosphate

Metaphosphates are salts of metaphosphoric acid that react with ammonia to form ammonium metaphosphate. Ammonium metaphosphate is also made by reacting phosphorus pentoxide with ammonia.

Ammonium metaphosphate is a white fluffy powder with about 80% phosphorus and 17% nitrogen.

Metaphosphoric acid or salts are often present in a polymerized form. In the vapor phase, the acid exists as a dimer and in solution it occurs as a trimer or tetramer.

## Ammonium molybdate

Ammonium molybdate,  $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 2\text{H}_2\text{O}$  is an important molybdenum fertilizer. It is an ammonium salt of molybdic acid and contains about 50% molybdenum.

Ammonium molybdate is generally mixed with NPK fertilizers, depending on the crop requirement (generally 50 to 1000 gm per ha). The fertilizer is also applied as a foliar spray, but coating or soaking seeds with ammonium molybdate is the easiest method of application, which requires very little fertilizer.

## Ammonium nitrate

Ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) is among the most common nitrogenous fertilizers, with half of its nitrogen in an ammoniacal form and the rest in nitrate form.

The nitrogen from ammonium nitrate is immediately available to plants, whereas the ammoniacal nitrogen becomes available only after its nitration. Fertilizer grade ammonium nitrate solution in water containing 20% nitrogen is sold in large quantities, because of its high water solubility and easy soil applicability. The fertilizer can also be used in its compound forms, such as calcium ammonium nitrate and ammonium sulphate nitrate.

The nitrogen in ammonium nitrate is more rapidly available than that in urea or ammonium sulphate. Crops take up nitrogen mainly in the form of nitrate. The ammoniacal nitrogen must be converted to nitrate in the soil before it becomes effective. Urea causes seedling damage due to volatilization of ammonia. Ammonium nitrate and ammonium sulphate are strongly acid-forming fertilizers.

Although pure salt ammonium nitrate is a fine white crystal, it is usually available as white granules or prills of 1.2 to 3.3 mm size and contains 32 to 35% nitrogen by weight. The crystalline form is highly hygroscopic and is readily soluble in water. Because of this high solubility in water, it is less effective for flooded rice than urea or other ammoniacal nitrogen fertilizers. It is also more prone to leaching than other ammoniacal products. It is also a very powerful oxidizing agent which can explode when exposed to heat or flame. Because of this hazardous property, ammonium nitrate and its compounds are stored in a dry place in sealed bags. The granular form, however, is easily stored. It can also be spread on soil with ease.

Ammonium nitrate, like other **ammonium fertilizers**, can leave behind an acid residue in the soil. It takes 0.8 kg of lime to neutralize the acidity produced by 1 kg of ammonium nitrate fertilizer.

Ammonium nitrate and urea are the most widely used sources of nitrogen from among all solid fertilizers available. A two bale crop of cotton removes 56 kg of nitrogen per hectare in the seed alone and 16.8 kg of nitrogen per hectare in the lint. To supply this amount of

nitrogen, the addition of 224 kg per hectare of ammonium nitrate is required. A 2240 kg per hectare tobacco crop removes 123 kg of nitrogen per hectare, and 5600 kg per hectare crop of rice removes 90 kg of nitrogen per hectare.

Ammonium nitrate is used as a major source of nitrogen for crops in the USA. It is a good nitrogen plant food for all field and vegetable crops and can be applied to the soil before or at the time of planting. It also makes for a good N-fertilizer for **side dressing** or **top dressing**.

An aqueous solution of urea and ammonium nitrate, called **UAN** is used as a liquid nitrogen fertilizer. 'Ammonite' is a trademark for a mixture of ammonium nitrate (98%) and coating agents (2%).

### Ammonium nitrate-lime fertilizer

Ammonium nitrate-lime fertilizer is a non-acid forming mixture of ammonium nitrate and lime. It is manufactured at Hopewell, Virginia, in the USA and is sold under the trade name 'ANL'. It contains 20% nitrogen, 10% calcium (as CaO) and 7% magnesium (as MgO.) It is usually prepared in a pellet or prilled form suitable for mixing, with other fertilizers, direct application and shipping out.

### Ammonium nitrate limestone

Ammonium nitrate limestone is a white to grey, chalky powder. It is also known as **calcium ammonium nitrate**, a nitrogenous fertilizer. If made from dolomitic limestone, it contains 20% nitrogen, 6% calcium and 4% magnesium. The color of the powder depends on the limestone used in the manufacturing process.

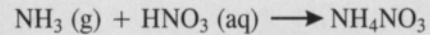
### Ammonium nitrate production processes

Ammonium nitrate is the most popular form of nitrogen fertilizer in Europe. It is being replaced by liquid fertilizers and anhydrous ammonia in Canada and the United States of America.

Ammonium nitrate contains 33 to 34% nitrogen, half of which is in an ammonium form and the remainder in a nitrate form. It is applied directly or in combination with calcium carbonate, limestone or dolomite. The combination is called **calcium ammonium nitrate** or

**ammonium nitrate-limestone (ANL.)** It is also an ingredient in many liquid fertilizers.

Ammonium nitrate is produced by several slightly different processes that utilize the basic product, ammonia, to produce nitric acid, which in turn is neutralized by more ammonia to form ammonium nitrate (Fig.A.29). The process chemistry is simple, the reaction between anhydrous ammonia and nitric acid being,



The reaction is highly exothermic and proceeds with high speed. The concentration of nitric acid used ranges from 45 to 60%, depending on the process. Except where ammonium nitrate is used as a liquid fertilizer, ammonium nitrate solution is concentrated and processed into prills or granules.

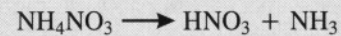
Ammonium nitrate is a strong oxidizer and can support combustion. When dry ammonium nitrate is heated between 170°C (melting point) and about 250°C, the following exothermic reaction occurs.



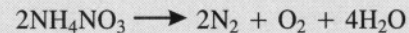
If the nitrogen dioxide gas is not allowed to escape freely, another highly exothermic reaction can occur.



Above 250°C, nitric acid and ammonia are formed. This reaction is endothermic.



The explosive decomposition of ammonium nitrate can be described by the following reaction:



Production technology of ammonium nitrate: Solid ammonium nitrate is produced as prills, granules or crystals. Its production involves the following steps: (a) neutralization, (b) concentration, (c) finishing, (d) process condensate treatment, and (e) vapor treatment with heat recovery.

(a) **Neutralization:** When sufficient steam is available, the use of an atmospheric type of neutralizer is preferred. Acids of more than 50% concentration are

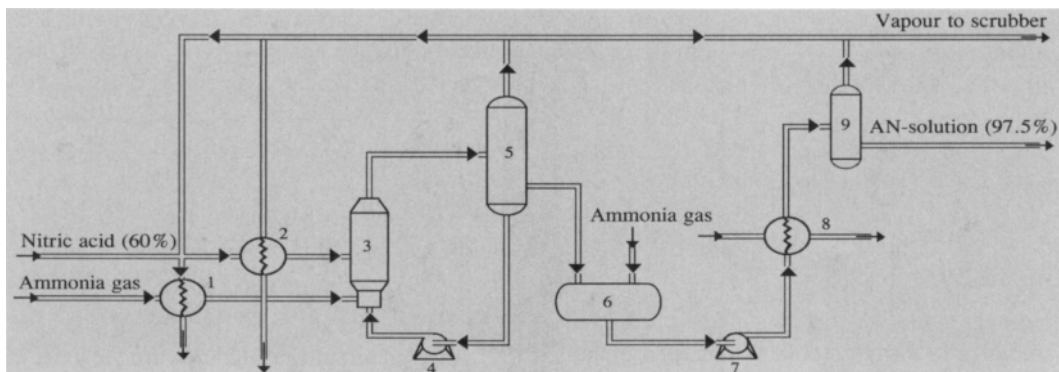


Fig.A.29: Flow chart of ammonium nitrate production 1. Ammonia preheater, 2. Nitric acid preheater, 3. Reactor, 4. Circulating pump, 5. Flash evaporator, 6. Neutralizer, 7. AN-pump, 8. Reboiler, 9. Flash evaporator. (Source: "Fertilizer Manual, 1998, UNIDO, IFDC and Kluwer Academic Publishers. The Netherlands. With permission.)

used for neutralization. When a crystalline product is desired, neutralizations are performed under vacuum. The temperature in the neutralizer for atmospheric pressure neutralization is low (about 145°C).

In a pressure-neutralized process, the neutralizer usually operates at a pressure of 4 to 5 atmosphere and at a temperature of 175 to 180°C. A 50 to 60% concentration of nitric acid is used. Ammonia is fed into the neutralizer in a gaseous form. The neutralizer is operated at a low pH of 3 to 4 to avoid loss of ammonia. More ammonia is added to adjust the pH to 7. The concentration of ammonium nitrate in the neutralized solution is in the range of 80 to 87%. It is evaporated further to a concentration of 94 to 98% by using steam. A final evaporator-concentrator is used to increase the concentration from 99.5 to 99.8%.

Practically all types of evaporators and separators are used in this process. Most fertilizer grade ammonium nitrate is treated with inorganic stabilizers to retard the 32°C crystal transition and to improve storage properties. The most popular salt used for phase stabilization is magnesium nitrate. It is added to hot ammonium nitrate solution prior to its reaching the final concentration. Other salts used as stabilizers include the sulphates of aluminum and iron, ammonium sulphate-calcium nitrate, ammonium phosphate and permalene-34 (a mixture of boric acid, diammonium phosphate and ammonium sulphate). Caking of the product is avoided by coating the prills and granules with very small amounts of anti-caking agents such as oil/amine mixtures.

Several finishing processes such as graining, flaking, granulation, crystallization and prilling are used. In low-density prilling, about 95% ammonium nitrate solution is fed into the prilling tower and the prills formed are cooled and dried. The prills are porous and have an apparent density of around 1.29 g/cm<sup>3</sup> compared to high-density prills with a density of 1.65 g/cm<sup>3</sup>. Low density prills are used in explosives and as blasting agents.

The high-density prilling process uses more than 99% concentrated solution of ammonium nitrate. This process needs expensive fume abatement equipment and has low flexibility for producing different nitrogen containing products. The product size is limited and the prills are less hard.

The granulation process, unlike the prilling process, has the advantage of producing different particle sizes. A rotary pan, a rotary drum and fluid bed processes are used in granulating ammonium nitrate.

**Industrial neutralization processes for ammonium nitrate:** Various industrial neutralization processes for ammonium nitrate are: (a) Uhde neutralization under vacuum or atmospheric pressure, (b) Uhde neutralization under 0.2 to 0.25 MPa pressure, (c) Hydro-agri neutralization under 0.4 to 0.5 MPa pressure, (d) Carnit neutralization at 0.7 to 0.8 Mpa, and (e) pipe reactor neutralization (AZF).

**Uhde neutralization** under vacuum or atmospheric pressure process calls for a relatively low investment cost. The 304L stainless steel reactor is slightly

pressurized to prevent ammonium nitrate solution from boiling due to the heat of the neutralization reaction. The ammonium nitrate solution is evaporated in a flash evaporator to remove some water and cooled to reach a 95% concentration of ammonium nitrate. The neutralization conditions are 0.03 to 0.12 MPa pressure and a temperature of 130 to 145°C. Uhde neutralization under 0.2 to 0.25 MPa pressure process was mainly developed to balance heat requirements. The heat of reaction is used to concentrate ammonium nitrate via a heat exchanger. In the **hydro-agri neutralization process**, neutralization is carried out under a pressure of 0.4 to 0.5 MPa and a temperature of 175 to 185°C. The process calls for reactors made of specialized materials like titanium or low carbon 304L.

The **CARNIT process** operates at 185°C at a reactor output pressure of 0.75 MPa. The neutralization is carried out in: (a) alkaline solution for which a low carbon stainless steel reactor is used, and (b) acidic solution for which a titanium reactor is installed. The alkaline hot solution passes through a steam boiler and a falling film evaporator made of low carbon stainless steel. The concentrated solution is recycled to the reactor where additional nitric acid is added before flashing and scrubbing.

In the **AZF-Grand Paroisse prilling process**, neutralization is carried out in a pipe reactor using gaseous ammonia and preheated nitric acid to directly give ammonium nitrate melt of up to 97% concentration. A concentrated 95 to 97% ammonium nitrate solution overflows from the tank to the pump tank. If the ammonium nitrate solution is less than 96%, it is first concentrated in a falling film evaporator.

The important industrial finishing processes include the (a) AZF-Grand Paroisse prilling process, (b) GIAP neutralization/prilling technology, (c) granulation processes, and (d) production of straight granulated ammonium nitrate.

In AZF Paroisse prilling, the ammonium nitrate solution from the pipe reactor (after the neutralization step) is first concentrated to 99.8% in an air swept falling film evaporator, with steam condensing in the shell. The solution is sprayed from the top of the prilling tower. Fans located at the top ensure a counter current flow of cooling air against the falling droplets. The prills are collected at the bottom for discharge to drying, cooling and screening operations. For porous ammonium nitrate prills, 95% solution is used to dissolve the off-specification material. The main producers of high density prills are Russia and other Republics of the erstwhile Soviet Union.

**GIAP neutralization/ prilling technology** is a high density prilling process. In this process, neutralization is carried out at 70 to 90°C to get 89 to 92% ammonium nitrate solution. This solution is further concentrated to 99.7 to 99.8% of ammonium nitrate and fed to the spray heads of special design to form 'uniform' prills. The spray heads in conjunction with a fluidized cooling bed can provide up to 85% prills of 2 to 3 mm diameter.

Stabilizers are added to the ammonium nitrate solution and the prills are conditioned prior to bagging. The main features of this process are its simple operation and high reliability.

The disadvantages of prilling are its difficult emission control, limited product size and lower product hardness. Granulation processes are flexible and allow easier emission control. Granulation gives a coarser product than prilling, thereby minimizing the segregation of bulk blended fertilizers.

The advantages of granules are that these are free flowing materials which allow mechanized handling and distribution; they also have a high bulk density, reduced amenability to dust formation and leaching losses. The particle size of prills (usually < 2.5 mm) is much smaller than that of granules. In addition, the crushing strength of prills is lower, their porosity higher and their bulk density lower. These physical properties imply unfavorable agronomic effects in fertilizer application techniques. Larger sized prills are possible only by increasing the tower height, which entails increased investment costs.

The following granulation processes are available for the production of straight ammonium nitrate (of 30 to 34.5% nitrogen content): (a) cold spheroidizers, (b) drum, (c) pug mill, (d) pan, (e) fluid bed, and (f) fluidized drum. However, the concentration of ammonium nitrate melts (wt %) is different, and is as follows: (a) drum, 96 to 96.5, (b) pug mill, 95.5 to 96, (c) pan granulation, >99.5, (d) fluid bed granulation, >99, and (e) fluidized drum granulation, >97.5. In all methods, additives are essential for granulation and for improving storage properties.

In the granulator, a hot, virtually moisture-free melt is sprayed onto the moving bed of solids to solidify on the cool particles. Round granules get formed by agglomeration. As the size increases, they move upwards and roll over the rim of the rotating pan. The granulation temperature is controlled by the rate at which the solids are fed into the pan. The recycle ratio is about 0.5/0.7:1 for ammonium nitrate. The granules formed have an irregular surface and are smoothed by cooling and polishing. The cooled granules are conveyed to a screen. Over-sized materials from the screen are fed to a crusher, and crushed materials, under-sized granules and dust from cyclones are recycled. A wet scrubber may be used for recovery.

The **fluidized drum granulation** process consists of a rotary drum fitted with lifters and a fluidized bed installed inside the granulator. It is swept with conditioned air as per the need. The seed material fed to the granulator undergoes a size increase, and cooling and/or drying, as the case may be, occurs in the granulator in a series of cycles. The number of cycles required to obtain the desired particle size is determined by the residence time in the drum and is controlled by an adjustable overflow threshold.

Various additions such as micronutrients, fillers or other specific additives can be added with the sprayed product. The heat balance and granulation behaviour

determine how much recycle material has to be dissolved in the ammonium nitrate melt and how much can be recycled as dry matter to the drum.

The **crystallization process** is very similar to the prilling process up to the point of evaporation. The liquor containing 80 to 85% solids is transferred from the vacuum evaporator to a vacuum crystallizer where crystal growth is controlled to yield large crystals for fertilizer use at about 40°C. The crystals along with the slurry are centrifuged. The crystals are dried in a rotary drier and the mother liquor is returned to the evaporator.

The **Stengel process** is based on vapor phase reaction in a packed stainless steel reactor. This process, which is not of commercial importance, produces a flaked product unlike the other processes, which give a spherical shaped pellet or granule.

Pollution control requirements have become stringent in recent times. This is more so for high-density ammonium nitrate prilling in view of high melt temperatures as well as the large volume of air exhausted from prill towers. The air fumes exhausted from the prilling tower contain very small particles of ammonium nitrate. Fuming is more severe in high-density prilling in view of the dissociation of ammonium nitrate at that temperature. The dissociated products recombine in the cooler parts and have particles of submicron size. The problem is less serious with low density prilling because of lower solution temperatures. Even in the granulation processes, the problem is less serious because of much smaller volumes of air being in contact with hot solution. The process vapors containing small amounts of ammonium nitrate and nitric acid may be freed from these impurities by means of droplet separators (demister pads, wave plate separators, etc.) and/or scrubbing systems (packed columns or venture scrubbers).

The emission of ammonium nitrate mists, which may also occur during the neutralization and evaporation processes are, however, difficult to remove due to their submicron size. The process vapors are normally condensed and purified by stripping, ion exchange or reverse osmosis. The exhaust air from prilling or granulation contains ammonia and ammonium nitrate and is not absorbed by applying the usual scrubbing methods and is quite visible as a persistent blue haze. Such a haze can have tremendous environmental consequences. To avoid this haze and to reduce emission of submicron ammonium nitrate aerosols, fiber mist eliminators are installed.

### Ammonium nitrate-pulverized dolomite

Ammonium nitrate-pulverized dolomite is a grey colored mixture of ammonium nitrate and pulverized dolomite. It is manufactured at Hopewell, Virginia, in the United States.

### Ammonium nitrate sulphate

Ammonium nitrate sulphate has two grades – 30-0-0-5(S) and 27-0-0-11(S). These two grades are available commercially in a granular form, and both are less

hygroscopic than ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ). The first grade contains 21% ammonium sulphate and 79% ammonium nitrate, and the second has 46.2% ammonium sulphate and 53.8% ammonium nitrate. These are made either by blending in bulk (for direct application) or by neutralizing a mixture of nitric acid and sulphuric acid with ammonia. The two salts, both fast and slow reacting fertilizers, are applied directly to forage, small grains, grass, seed crops, etc.

### Ammonium nitrophosphate

Ammonium nitrophosphate is another name for **ammonium phosphate nitrate**.

### Ammonium orthophosphates

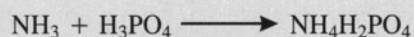
Ammonium orthophosphates are important members of the phosphate fertilizer family, formed by the reaction of anhydrous ammonia with orthophosphoric acid ( $\text{H}_3\text{PO}_4$ ). Monoammonium phosphate (**MAP**) and diammonium phosphate (**DAP**) are the two major forms of ammonium orthophosphates.

Ammonium orthophosphates are applied to soil either directly, or as a solution, or in a suspension form, depending on the proportion of insoluble phosphates present in the soil.

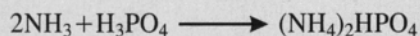
### Ammonium phosphate

Ammonium phosphates refer to a generic class of phosphorus fertilizers and are manufactured by reacting anhydrous ammonia with orthophosphoric acid or superphosphoric acid. These are either in solid or liquid form.

Anhydrous ammonia added to liquid phosphoric acid gives monoammonium phosphate (**MAP**) which contains about 11% nitrogen and 21% phosphorus vide the reaction:



With more ammonia, technical grade diammonium phosphate (**DAP**) containing 16 to 18% nitrogen and 20 to 21% phosphorus is formed by the reaction:



Ammonium phosphate fertilizers are highly soluble in water and fast acting in soil to give nitrogen and phosphorus in a chemical combination. They form an important base for many compound fertilizers.

Both mono and diammonium phosphates have good physical properties when synthesized from the wet-process phosphoric acid. Storage properties and the ease of granulation depends on the amount of impurities, which form a gel like structure (mainly aluminum and iron phosphates). This gel promotes granulation and serves as a conditioner to prevent caking even at moderately high moisture levels. A small proportion of phosphate rock added to phosphoric acid before ammoniation improves the granulation.

Ammonium phosphates, particularly diammonium phosphates (**DAP**), are the most popular phosphate fertilizers worldwide because of their high utility and good physical properties. The standard **commodity grade of diammonium phosphate** is 18-46-0. Pure and completely soluble ammonium phosphates are used mainly as liquid fertilizers. In Britain, diammonium phosphate is not sold directly in this form, but is used to make compound fertilizers with a wide variety of plant foods. **DAP** contains 21% nitrogen and 23% phosphorus (54%  $\text{P}_2\text{O}_5$ ).

Diammonium phosphate is unstable at temperatures above  $150^\circ\text{C}$  while monoammonium phosphate remains stable even at much higher temperatures. These two fertilizers usually form a part of concentrated compound fertilizers and are rarely used individually in their pure states.

Granular **DAP** is commonly produced by a slurry process, developed by TVA (Tennessee Valley Authority) or the Jacobs-Dorrco Industrial Process. In the wet process, acid of about 40% phosphorus pentoxide ( $\text{P}_2\text{O}_5$ ) is reacted with ammonia in a preneutralizer where the mole ratio of  $\text{NH}_3:\text{H}_3\text{PO}_4$  is controlled at about 1.4. The heat of the reaction raises the slurry temperature to boiling point (about  $115^\circ\text{C}$ ). The hot slurry containing about 16 to 20% water is pumped into the granulator, where more ammonia is added to increase the molar ratio to approximately 2.0. Moist granules are dried, screened and cooled, while the undersized and crushed oversized ones are recycled. Escaping ammonia is recovered by scrubbing with weak acid. The same equipment is used to produce monoammonium phosphate, wherein the preneutralizer is operated at a molar ratio of about 1.4. The phosphoric acid is then added into the granulator to decrease the ratio to 1.0.

Pure monoammonium phosphate is completely water-soluble and contains 12% nitrogen and 21% phosphorus (as 52%  $\text{P}_2\text{O}_5$ ). The production of non-granular monoammonium phosphate has been achieved by a number of processes developed for use as an intermediate in the production of complex fertilizers, by Scottish Agricultural Industries, Fison's Ltd., Swift Agricultural Chemicals, Nissan and ERT Espindesa to name a few. In general, all processes aim at a simple, low cost method by eliminating granulation, recycling and drying. Though the production of powdered monoammonium phosphate is on the decline, it is still in use because of its high phosphorus content (as  $\text{P}_2\text{O}_5$ ).

In addition, a group of fertilizers, such as ammonium phosphate-sulphates, **ammonium phosphate-chloride** and ammonium phosphate-nitrate are produced by a number of processes involving the neutralization of ammonia with a mixture of phosphoric acid and plant waste acids like sulphuric acid, nitric acid or hydrochloric acid. These fertilizers are free flowing and non-hygroscopic (or less hygroscopic) compared to the individual components, and have been successfully used in many types of soils.



**Ammonium phosphate chloride:** See Ammonium phosphate

### Ammonium phosphate nitrate

Ammonium phosphate nitrate (APN), also called **nitric phosphate** or **ammonium nitrophosphate**, is an acidic fertilizer produced by reacting phosphate rocks with nitric acid. It contains nitrogen in ammoniacal and nitrate forms and phosphorus as phosphate. APN is made either by the **Odda route** or by the **mixed-acid route**, covering a range of formulations with N:P<sub>2</sub>O<sub>5</sub> ratios between 0.5 and 2.0. The most popular formulations are 20-20-0, 25-25-0, 20-10-10, 15-20-15 and 12-24-12, where the equivalent acidity is about 491 kg of calcium carbonate (CaCO<sub>3</sub>) per ton of the fertilizer.

Nitrophosphates are manufactured in granular form for direct application or blending. Calcium nitrate, which is a hygroscopic reaction product, is removed by refrigeration and centrifugation, or is converted to calcium carbonate by injecting carbon dioxide. Some processes employ sulphuric or phosphoric acid, along with nitric acid, to convert a part of the calcium nitrate to calcium sulphate or calcium phosphate. The acidified slurry is then ammoniated. The final product contains an assortment of salts.

The water solubility of nitric phosphates may vary from 0 to 80%, depending on the process used. Nitric phosphate containing 30% or less water-soluble phosphorus is thus not a recommended fertilizer for plants that respond to such phosphorus. Nitric phosphates give best results on acidic soils. They are suitable for turf and sod crops, and sugar cane which has a relatively long growing season.

There are several processes involved in the production of fertilizers containing ammonium phosphate and ammonium nitrate. Most of these are used to produce NPK grades. A slurry of concentrated ammonium nitrate solution (97%) and ammonium phosphate is used to produce ammonium phosphate nitrate in a rotary drum granulator in the **Pechiney-Saint-Gobain process**. The principal product is 17-17-0. Tennessee Valley Authority (TVA) process produces grades of 25-25-0 and 30-10-0. The production rate is 20 t/hour. In **AZF-Grande Paroisse dual pipe-reactor process**, ammonium nitrate solution is directly sprayed on granules in the granulator. APN solutions are made by neutralizing phosphoric acid with NH<sub>3</sub> and NH<sub>4</sub>NO<sub>3</sub>.

### Ammonium phosphate sulphate

Ammonium phosphate sulphate (APS), a complex nitrogen-phosphorus-sulphur fertilizer, is composed of 60% ammonium sulphate and 40% ammonium phosphate. It is granular, water-soluble and light grey in appearance. It has good keeping properties and leaves an acid effect on the soil because of ammoniacal nitrogen and sulphate anions.

APS is a popular fertilizer in some areas like the southern parts of India, owing to its non-hygroscopic

nature and sulphur content. It is agronomically useful for many crops.

The ammoniacal nitrogen in APS cannot be easily washed away from the soil, because of its adsorption by the soil colloids. Crops like paddy, sugar cane, cotton and potato utilize the ammoniacal form of nitrogen. The phosphorus in APS is water-soluble and suitable for all types of crops (especially short duration crops), as a source of sulphur is present in it to the extent of 15%.

Table-A.5 shows specifications of two grades of ammonium phosphate-sulphate, produced in India.

Table-A.5: APS specifications of two grades in India

Specifications	APS	
	Grade 16-20-0	Grade 20-20-0
Moisture (percent, maximum)	1.0	1.0
Total N (weight percent, minimum)	16.0	20.0
Total ammoniacal N (percent, minimum)	16.0	18.0
Nitrogen in the form of urea (weight percent, maximum)	-	2.0
Ammonium citrate-soluble phosphates (as P <sub>2</sub> O <sub>5</sub> ) - neutral (minimum)	20.0	20.0
Water-soluble phosphate as P <sub>2</sub> O <sub>5</sub> (weight percent, minimum)	19.5	17.0
Particle size: 90 percent of the material should pass through 4 mm IS sieve and retain on 1 mm IS sieves. More than 5% material should not have a diameter smaller than 1 mm. Sulphur is generally not specified.		

Source: "Sulphur Fertilizers for Indian Agriculture-A guide book", Edited by HLS Tandon. Fertilizer Development and Consultation Organisation, New Delhi. With permission.

Ammonium phosphate sulphate is produced by two methods. In the first, a mixture of sulphuric and phosphoric acids is neutralized by ammonia before the resulting slurry is granulated. To achieve this, phosphoric acid, sulphuric acid and ammonia are introduced, using appropriate metering and control mechanisms, into the first reaction tank. In the second reaction tank, a finer pH adjustment is made by adding an appropriate amount of ammonia. The neutralized slurry, ammoniated to a mole ratio of 1.8 or 2% and urea are added to raise the nitrogen content to 20%, and granulated. The granules are dried by hot air and screened by double-decked vibrating screens. This results in a granulated free flowing APS.

In the second method, ammonium-sulphuric acid solution from the gypsum ammonium carbonate process is added to phosphoric acid and then the mixture is ammoniated. Again, urea is added, as in the first method, to bring the nitrogen content to the required level. When a 20-20-0 grade is required, an allowance of 2% in ammoniacal nitrogen (18% minimum) is made to accommodate the nitrogen in the form of urea (2%



maximum). A total nitrogen content of 20% is also stipulated. When a 16-20-0 grade is required, the entire nitrogen (16%) is specified to be in the ammoniacal form, whereas for water-soluble phosphate, the minimum stipulated concentrations of nitrogen are 19.5% for the 16-20-0 grade and 17% for the 20-20-0 grade. The sulphur content often remains unspecified in the Fertilizer Control Order (FCO).

### Ammonium polycarboxylate

Polycarboxylic acid is an organic acid containing two or more carboxyl groups in a molecule. The ammonium salt of any polycarboxylic acid is called ammonium polycarboxylate. Coal distillation gives carboxylic acids which, on ammoniation, can be used as a fertilizer or blended with other fertilizers.

### Ammonium polyphosphate

Ammonium polyphosphate (APP) is made by ammoniating hot superphosphoric acid containing about 79% phosphorus pentoxide. It is also produced by a direct reaction of anhydrous ammonia with orthophosphoric acid, eliminating water. It has good storability and can be pumped out when required. The solid granular fertilizer contains 15% nitrogen and 62% phosphorus (as  $P_2O_5$ ).

Ammonium polyphosphate is used to produce complete liquid fertilizers for direct application. Both liquid and solid ammonium polyphosphates are available. A nitrogen-phosphorus-potassium grade, using the mixture plus muriate of potash and nitrogen solution, is 5-5-8 (N:P:K). The fertilizer contains ammonium orthophosphate, ammonium pyrophosphate and some longer chain polyphosphate components. When applied directly, the crop response is similar to that with liquid fertilizers or water-soluble dry fertilizers. When water solubility of phosphorus is important, liquid fertilizers are considered superior to solid fertilizers that contain some amount of water-insoluble phosphorus. Ammonium polyphosphate is a **chelating agent** as it maintains a higher concentration of micronutrients than is possible with orthophosphate solutions. For example, ammonium polyphosphate can maintain 2% zinc in solution as compared to 0.05% zinc with phosphates.

The process for producing granular ammonium polyphosphate uses heat of reaction of phosphoric acid (54%  $P_2O_5$ ) with gaseous ammonia to evaporate the water and dehydrate ammonium phosphate, forming a melt. The melt, which can be granulated, usually contains 15 to 25%  $P_2O_5$  as polyphosphate, but it can be increased to almost 50% by preheating the acid and ammonia, or by using a more concentrated phosphoric acid. The melt is granulated in a pugmill or a rotary granulator. The advantage of the process is that the product has very low moisture content and needs no drying. In addition, the products have good storage properties.

Polyphosphate, before being taken up by crop plants, must undergo hydrolysis to form orthophosphates. The hydrolysis is brought about by enzymes such as

pyrophosphatase, which are present in the soil. The half-life of the polymeric forms of phosphorus in liquid ammonium polyphosphate is 1.6 to 2.0 days under anaerobic conditions and 5.2 to 8.7 days under aerobic conditions. The corresponding values of solid ammonium polyphosphate are 3.9 to 9.2 days under anaerobic and 12.5 to 27.0 under aerobic conditions.

It is established that hydrolysis rate is highest in laterite, intermediate in sodic and slowest in alluvial soils. The soil factors that affect hydrolysis are pH, temperature, texture and water content. (See also Polyphosphate fertilizers.)

### Ammonium polysulphide

Ammonium polysulphide exists only in solution. It is made by passing hydrogen sulphide through a 28% ammonium hydroxide solution and then dissolving additional sulphur in the resulting solution. This solution, which is red to brown to black in color, contains about 45% sulphur and 20% nitrogen and has the odor of hydrogen sulphide. It can be mixed with other liquid fertilizers like anhydrous ammonia, aqua ammonia and urea-ammonium nitrate solutions.

To ensure reasonable stability, the mixed liquid fertilizer should not contain more than 10% of ammonium polysulphide, as it is incompatible with polyphosphate containing liquids.

Ammonium polysulphide is stored under pressure (0.1 kg/cm<sup>2</sup>), in view of its high vapor pressure. It is stored under pressure also to prevent the loss of ammonia and the precipitation of sulphur. It is also used for reclaiming highly acidic soils and for treating irrigation water. Another instance of polysulphide is potassium polysulphide [0-0-22-23(S)], which is used in sprinkler and flood irrigation systems, to remove salts and supply potassium.

### Ammonium pyrophosphate

Ammonium pyrophosphate is a phosphate fertilizer based on non-orthophosphoric acid. Its common grade is 10-34-0. It is made by reacting pyrophosphoric acid with ammonia.

Pyrophosphoric acid is made by dehydrating phosphoric acid obtained by the wet acid process (Fig.A.30). Polyphosphate denotes two or more orthophosphate ions ( $H_2PO_4^-$ ) combined after the loss of a water molecule per two orthophosphate ions; the simplest form is the pyrophosphoric acid, ( $H_4P_2O_7$ ).

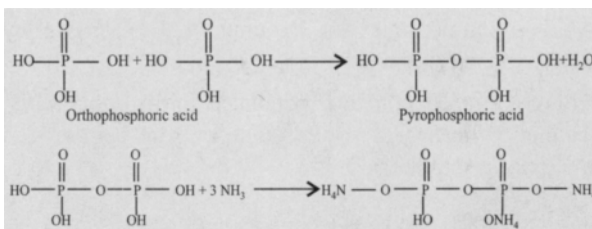


Fig.A.30: Chemical reactions involved in the formation of pyrophosphoric acid and ammonium pyrophosphate.

Triammonium polyphosphate is a liquid containing 10 to 15% nitrogen and 15 to 16% phosphorus (or 34 to 37%

P<sub>2</sub>O<sub>5</sub>). Granulation during manufacture results in a solid product 11-55-0 which can be applied directly or blended with other granular fertilizers. The addition of a 99.5% urea solution gives a granular urea-ammonium polyphosphate, called **urea-ammonium polyphosphate (UAP)**, with a product composition of 28-28-0 which has 100% water-soluble phosphorus. Liquid ammonium polyphosphate is more popular and is applied either directly or mixed with other liquid fertilizers.

Ammonium polyphosphates are known for their ability to chelate or sequester metal cations. They maintain a higher concentration of micronutrients – 2% zinc ion as against orthophosphate solution, which holds a mere 0.05% zinc ion. (Fig. A.31).

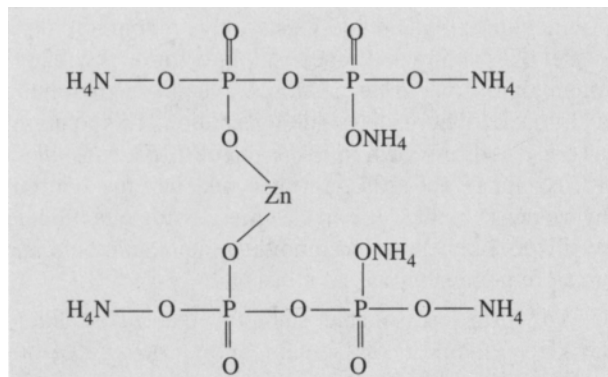


Fig. A.31: Zinc chelate of ammonium pyrophosphate.

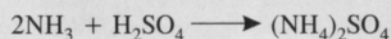
### Ammonium sulphate

Ammonium sulphate, (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, a water-soluble crystalline salt is a nitrogenous fertilizer containing about 21% nitrogen and 24% sulphur. It occurs naturally as the mineral mascagnite and offers many advantages as a fertilizer, such as low hygroscopicity, good physical properties, excellent chemical stability, good agronomic effectiveness and long shelf life.

Ammoniacal nitrogen is fixed in the soil in an exchangeable form until nitrated by nitrifying bacteria. The ammoniacal nitrogen of ammonium sulphate does not leach out easily. Ammonium sulphate is an acid forming fertilizer, and hence used in neutral or alkaline soils. In its free flowing form, it is directly applied to the soil or blended with other granular materials. Ammonium sulphate also supplies sulphur, which is an essential nutrient for plants.

Ammonium sulphate is a quick-acting fertilizer. It is resistant to leaching as it gets adsorbed on the soil colloids, clay and humus, and replaces calcium. This adsorbed ammonium salt is converted to nitrate by nitrifying bacteria for use by growing plants.

Ammonium sulphate is produced in different ways. The major ones are: (i) Production from synthesized ammonia and sulphuric acid.



(ii) Production of ammonium sulphate fertilizer by the **gypsum process** is widely used in many developing countries. In this process, ammonia is used along with

pulverized calcium sulphate, carbon dioxide and water. Here ammonia made from nitrogen and hydrogen, reacts with carbon dioxide gas to produce ammonium carbonate. Ground gypsum reacts with ammonium carbonate solution to form ammonium sulphate and calcium carbonate.



Ammonium sulphate is commonly transported in polythene or paper bags. It is adsorbed on soil colloids, clay and **humus**, replacing calcium. It is more beneficial than nitrate fertilizers at planting time. This adsorbed portion is slowly released and in about a month most of the ammonium sulphate is converted into the nitrate form, which is used by growing plants.

Since rice crops absorb nitrogen even in the ammoniacal form, ammonium sulphate fertilizer is used as a source of nitrogen for rice in the USA and Southeast Asia. In the USA, ammonium sulphate is also used for potato scab control.

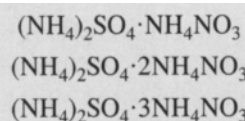
The main disadvantages of ammonium sulphate are its acid forming nature, low nitrogen percentage (21%) and high costs for packaging, storage and transportation.

### Ammonium sulphate nitrate

Ammonium sulphate nitrate, (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>·NH<sub>4</sub>NO<sub>3</sub> is a double salt fertilizer formed by the neutralization of waste acid by ammonia and subsequent crystallization. It has a higher nitrogen content (about 26%) than ammonium sulphate (21%), and can make soil acidic.

Ammonium sulphate nitrate (ASN) is a less hygroscopic fertilizer than ammonium nitrate and thus solves the problem of disposing waste acid and liquors produced in nitrating reactions.

Mixing moist salts containing 62.5% ammonium sulphate and ammonium nitrate also produces ammonium sulphate nitrate. The following three double salts are used routinely.



If a small quantity (1%) of ferrous sulphate is added during crystallization, ammonium sulphate nitrate is obtained as a free flowing solid; otherwise, it sets into a hard cake during storage.

Tennessee Valley Authority (TVA) produces ammonium nitrate-sulphate containing 30% nitrogen, mainly (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>·3NH<sub>4</sub>NO<sub>3</sub>, by ammoniation of a mixture of nitric-sulphuric acid, followed by pan granulation of the resulting slurry. Its storage properties are superior to those of the individual components.

### Ammonium sulphate production processes

The use of ammonium sulphate as a fertilizer is relatively small compared to that of urea, ammonium nitrate, UAN solutions and anhydrous ammonia.

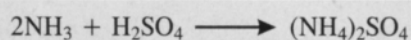
The crystal size of ammonium sulphate is governed by the requirement and type of application envisaged by the customer. For bulk blending or direct use in fertilizer, large crystals of 1 to 3 mm are preferred; somewhat smaller crystals are acceptable for direct application. Operating experience as well as additives may be needed to obtain crystals of the desired size.

The factors that contribute to good storage of ammonium sulphate and related fertilizer salts are the following: (i) The product should be of uniform size with a low percentage of fines and less than 0.1% moisture. (ii) The product should not have any free acidity. (iii) The product should be cooled with dry air under controlled conditions after drying, to avoid moisture condensation.

Several methods are used for ammonium sulphate manufacture, depending on local conditions and the availability of raw material. The principal methods are as follows:

- (i) Reacting ammonia and sulphuric acid in a reactor/evaporator under atmospheric pressure or vacuum, and recovering the crystals by filtering or centrifuging.
- (ii) Scrubbing coke-oven gas or tower gas with sulphuric acid in a specially designed reactor and recovering the crystals via centrifuging or filtration.
- (iii) Reaction of ammonium carbonate with gypsum, removal of the precipitated calcium carbonate by filtration, evaporation and crystallization of ammonium sulphate, followed by centrifuging the liquor.
- (iv) Evaporating the by-product solution containing ammonium sulphate produced from other processes such as caprolactam manufacturing unit, and separating the almost pure salt by crystallizing and centrifuging or recovering by slurry granulation.
- (v) Directly reacting gaseous ammonia with sulphuric acid in a spray tower to form anhydrous ammonium sulphate.
- (vi) Simultaneous production of ammonium sulphate and other ammonium salts containing multinutrients in granulated fertilizer processes.
- (vii) Other miscellaneous processes such as recovering ammonium sulphate from sulphur dioxide in flue gas or in sulphuric acid tail-gas.

(i) **Direct neutralization:** Anhydrous ammonia and strong sulphuric acid are reacted in a continuous saturator-crystallizer unit operating under vacuum or atmospheric pressure as follows:



Ammonia and sulphuric acid are introduced via a slurry recycle line, wherein they react and superheat the recycling slurry. The slurry is subsequently flashed in the upper chamber at a reduced pressure (generally between 55 and 58 cm of mercury). The exothermic heat of reaction is removed by evaporating water either present in the feed acid or added to the system for temperature control of the process. The loss of water in this zone

super-saturates the slurry which recirculates to the lower suspension vessel via an internal pipe and comes into contact with small crystals and nuclei. This induces further crystal growth in terms of size rather than in number. The slurry is recycled by a thermal syphon and/or by an external pump.

This type of crystallizer is generally known as 'Krystal' or 'Oslo unit'. During operation the pH control is required to be maintained within close limits (3.0 to 3.5), as otherwise, thin crystals result. The excessive acidity promotes an overgrowth of crystals in the pipelines. A higher pH or a lower acidity leads to inferior crystals which are difficult to wash and store and may cause ammonia losses as well.

In another type of reduced-pressure crystallizer with a draft tube battle unit, growing crystals are brought to the surface of the flashing slurry. At this surface, super-saturation induces maximum crystal growth, and sufficient nuclei are present to minimize the scale formation inside the unit.

Several types of atmospheric pressure units are preferred to a vacuum crystallizer because of their simplicity and lower capital cost. Ammonia is added via a jet-type mixer or a sparger tube. In another design, a simple absorption column incorporating a few large slotted bubble-hoods is used. In some other cases, a single vessel is employed for both reaction and crystallization and the heat of reaction is removed by evaporation of water. There are designs where separate vessels for reaction and crystallization are used for easy operation and closer control. An optimum balance between the cooling-air energy and the yield of crystals is obtained when the crystallization temperature is in the range of 63 to 66°C.

In most cases, the product is recovered from ammonium sulphate slurry by continuous or automatic batch type centrifuge. The product is washed with water and very dilute ammonia and spin-dried again before drying. For small output, top-feed filters are used since the product can be separated, washed and dried in a single equipment.

Ammonium sulphate liquor is corrosive and wetted parts of the equipment are made of stainless steel or rubber lined mild steel. To improve the shape and size, modifiers are used, such as trivalent metallic salts. Small amounts of phosphoric acid or arsenic compounds are added as corrosion inhibitors.

(ii) **Scrubbing of coke-oven gas or town gas:** Bituminous coals used for gas and coke production contain about 1 to 2% nitrogen as ammonia and the ammonia is recovered (2.5 to 3.0 kg of ammonia per ton of coal used). This ammonia byproduct is associated with high temperature carbonization as in coking plants for iron and steel production. However, in view of the low returns for this operation, recovery of ammonia as ammonium phosphate, ammonium thiocyanate, ferrocyanide, pyridines or tar is being attempted.

Three methods are known for ammonia or ammonium sulphate recovery: direct, indirect and semi-direct.

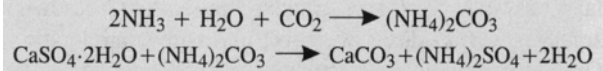
In the **direct method**, the whole gas stream is cooled to remove tar and then passed through a saturator where it is washed with sulphuric acid. The ammonium sulphate slurry is then centrifuged, washed, dried and stored. The advantages of this process are high recoveries with low effluents, low investment and low operating costs (including low steam needs). However, in many cases the product is contaminated with tar and pyridines. Where the same reactor is used as a scrubber and crystallizer, flexibility regarding the size, shape and the purity of the product suffers because of the difficulty in maintaining the pH and free acidity required to suppress impurities.

In the **indirect method**, the gases are cooled (by recirculating wash liquor and scrubbing) and passed through a bubble-cap type still to release free ammonia from salts. This free ammonia is either stripped with water to get ammonia solution or is sent to a sulphuric acid washer for getting ammonium sulphate. The advantages of this method are that (a) the ammonium sulphate produced is free from impurities, and (b) the process is flexible and can be used to also make aqua ammonia and its derivatives. However, effluent disposal problems are high and so are ammonia losses due to incomplete reaction and absorption.

The **semi-direct process** is a compromise between the direct and indirect methods. The gas is first cooled and washed to remove tar and other condensates. The ammonia released from the small ammonia still is combined with the main gas stream and heated to 70°C. This gas is scrubbed with a nearly saturated solution of ammonium sulphate containing 5 to 6% sulphuric acid at about 50 to 70°C. This process gives higher ammonia recoveries than those attainable by any other process.

(iii) **Ammonium-carbonate-gypsum process:** This method, also known as the **Merseburg Process**, combines ammonia and carbon dioxide to produce

ammonium carbonate, which is then reacted with gypsum or anhydrite to yield ammonium sulphate and calcium carbonate in an exothermic reaction (Fig. A.32).



The exothermic process has many advantages, such as the production of calcium carbonate as a byproduct which is used in cement production and agriculture. This process does not require any sulphur supply. The major disadvantage is the large energy (steam) requirement for ammonium sulphate recovery from a dilute solution.

At the Sindri plant in India, ammonia is absorbed in water and carbonated at a pressure of about 2.1 kg/cm<sup>2</sup> in a series of two aluminum towers. The prepared liquor strength corresponds to approximately 170 g of ammonia and 225 g of carbon dioxide per litre. In the FACT (Fertilizers And Chemicals Travancree Ltd.), India, jet absorbers are used for preparing ammonia solution and ammonium carbonate liquor in conjunction with a carbonating tower.

Natural gypsum or anhydrite, when used, is ground so that about 90% of the material passes through a 120 mesh sieve. When the byproduct gypsum of phosphoric acid plant is used, the impurities are removed by repulping the filter cake prior to washing and dewatering on a drum or disc filter.

Reactions of ammonium carbonate and gypsum solutions are carried out in a series of wooden vessels or mild steel vessels having steam coils and agitators to give a total retention time of 4 to 6 hours. The slurry produced is filtered and the calcium carbonate cake washed and dewatered. The solution is evaporated and the crystals are centrifuged and dried in a rotary drier at 120°C.

(iv) **Recovery from industrial byproduct liquors:** Ammonium sulphate is recovered from the waste streams of caprolactum, acrylonitrile and certain other processes

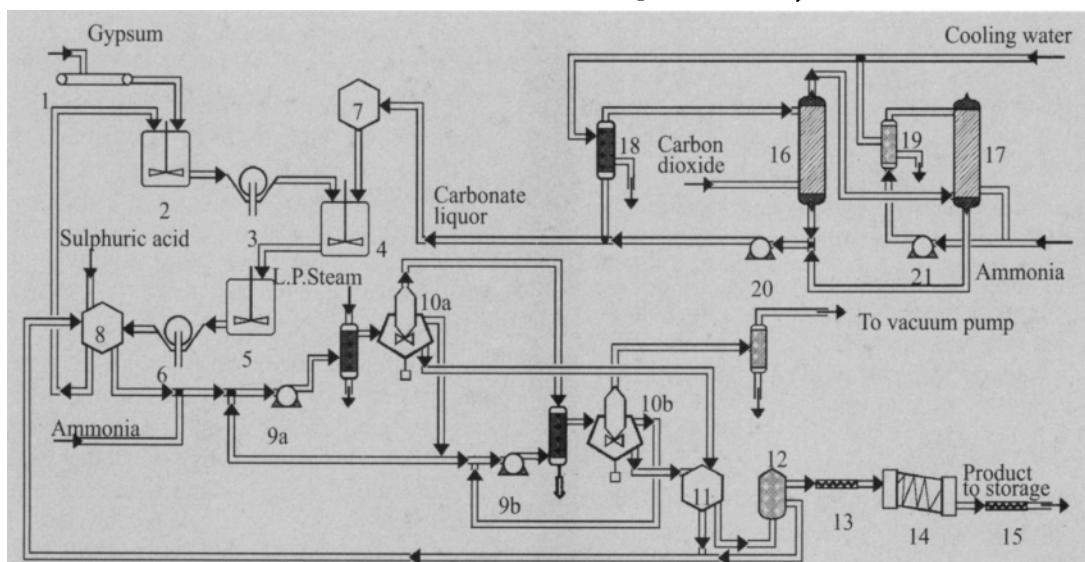


Fig. A.32: Flow chart of the gypsum process of ammonium sulphate production. 1. Gypsum conveyor, 2. Gypsum washing tank, 3. Gypsum dewatering filter, 4. Primary reactor, 5. Secondary reactor, 6. Calcium carbonate filter, 7. Ammonium carbonate storage tank, 8. Sulphate liquor clarifier, 9a and 9b. Evaporator feed pumps, 10a and 10b. Vacuum evaporator crystal, 11. Slurry concentrator, 12. Batch or continuous centrifuge, 13. Dryer conveyor, 14. Rotary dryer, 15. Product conveyor, 16 and 17. Ammonium carbonate towers, 18 and 19. Heat exchangers, 20 and 21. Pumps. (Source: "Fertilizer Manual, 1998, UNIDO, IFDC and Kluwer Academic Publishers. With permission.)

first by concentrating the liquor to around 35% ammonium sulphate. The ammonium sulphate is recovered from the slurry by centrifuging and drying. The process, which is uneconomical because of low concentrations of ammonium sulphate, produces around 1.8 to 4.0 tons of ammonium sulphate per ton of caprolactam.

(v) **Spray-tower ammoniation:** A good amount of ammonium sulphate is made in Japan from spray towers from sulphuric acid and anhydrous ammonia. The acid is sprayed on ammonia vapor inside the tower. The heat of reaction produces a dry amorphous product of less than 300 mesh size. This ammonium sulphate, suitable for granular compound fertilizers, is recovered from the tower by a screw conveyor.

(vi) **Mixed salt production:** Mixed salts of ammonium sulphate and ammonium nitrate are made by ammoniating a mixture of sulphuric acid and nitric acid or by combining these ammonium salts in special ways. Three double salts have been identified and these are  $(\text{NH}_4)_2\text{SO}_4 \cdot \text{NH}_4\text{NO}_3$ ,  $(\text{NH}_4)_2\text{SO}_4 \cdot 2(\text{NH}_4)\text{NO}_3$ , and  $(\text{NH}_4)_2\text{SO}_4 \cdot 3\text{NH}_4\text{NO}_3$ .

One German process produces  $(\text{NH}_4)_2\text{SO}_4 \cdot \text{NH}_4\text{NO}_3$  containing 62% ammonium sulphate and 38% ammonium nitrate, by ammoniating the requisite mixture of sulphuric and nitric acids. The mixture is evaporated to a moisture content of 3%. About 1% ferrous sulphate is added to prevent caking. The double salt is granulated after spraying ammonia solution.

In a simpler process, ammonium nitrate solution is evaporated to 95% concentration, cooled to 130°C and reacted with solid ammonium sulphate in a pug mill granulator until a pH of 4.0 is attained. The product is then dried, cooled and bagged. Prilling can also be adopted.

The Tennessee Valley Authority (TVA) produced ammonium sulphate - ammonium nitrate which contains 30% nitrogen. It is used mainly for sulphur-deficient areas. This product is also made by ammoniation of a mixed acid followed by pan granulation of the resulting slurry. Its storage properties are superior to ammonium nitrate or a mixture of solid ammonium nitrate - ammonium sulphate since free ammonium nitrate is absent.

When mixtures of sulphuric acid and phosphoric acid are ammoniated, a variety of mixed and double-salt products can be made. One of the popular compositions is 'ammophos' containing 16% nitrogen (N) and 20% phosphorus (as  $\text{P}_2\text{O}_5$ ). The ammoniated slurry is granulated in a pug mill or a drum unit, then dried and screened. The mixed salt has good storage properties under normal conditions.

Many methods have been developed to recover sulphur from the flue gas, involving scrubbing with ammonia or injection of ammonia into flue gas. From these reactions, ammonium sulphite, bisulphite, sulphate and their mixtures result. Because the demand for ammonium sulphate fertilizer is low, the sulphur from the flue gases is disposed off as calcium sulphate.

## Ammonium sulphate recovery by the direct method

Three methods are known for ammonia or ammonium sulphate recovery: **direct**, **indirect** and **semi-direct methods**.

In the direct method, the whole gas stream is cooled to remove tar and then passed through a saturator, where it is washed with sulphuric acid. The ammonium sulphate slurry is then centrifuged, washed, dried and stored. The advantages of this process are high recoveries and low effluents, low investment and operating costs including low steam needs. However, in many cases the product is contaminated with tar and pyridines. Where the same reactor is used as a scrubber and crystallizer, flexibility regarding the size, shape and the purity of the product suffers because of the difficulty in maintaining the pH and free acidity required to suppress impurities. (See also Scrubbing of coke-oven gas in the production of ammonium sulphate.)

## Ammonium sulphate recovery by the indirect method

Three methods are known for ammonia or ammonium sulphate recovery: **direct**, **indirect** and **semi-direct processes**.

In the indirect method, gases are first cooled (by recirculating wash liquor and scrubbing) and passed through a bubble-cap type still to release free ammonia from salts. This free ammonia is either stripped with water to get ammonia solution or is sent to a sulphuric acid washer for getting ammonium sulphate. The advantages of this method are that (a) the ammonium sulphate produced is free from impurities and (b) the process is flexible and can also be used to make aqua ammonia and its derivatives. However, effluent disposal problems are high and so are losses of ammonia due to incomplete reaction and absorption. (See also Scrubbing of coke-oven gas in the production of ammonium sulphate.)

## Ammonium sulphate recovery by the semi-direct method

Three methods are known for ammonia or ammonium sulphate recovery: **direct**, **indirect** and **semi-direct processes**.

The semi-direct process is a compromise between the direct and the indirect methods. The gas is first cooled and washed to remove tar and other condensates. The released ammonia from the small ammonia still is combined with the main gas stream and heated to 70°C. This gas is scrubbed with a nearly saturated solution of ammonium sulphate containing 5 to 6% sulphuric acid at about 50 to 70°C. This process gives higher ammonia recoveries than those attainable by any other process. (See also Scrubbing of coke-oven gas in the production of ammonium sulphate.)

## Ammonium taranakite

Ammonium taranakite is ammonium aluminum phosphate,  $\text{Al}_5(\text{NH}_4)_4\text{HO}(\text{PO}_4)_6 \cdot \text{H}_2\text{O}$ . **Taranakite**

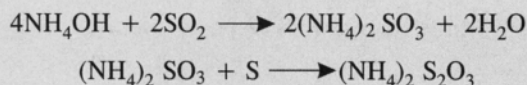
represents a group of products formed by phosphate fertilizers reacting with soil constituents.

### Ammonium thiosulphate

Ammonium thiosulphate,  $[(\text{NH}_4)_2\text{S}_2\text{O}_3]$  or **ATS** is a crystalline salt, the aqueous solution of which is commonly used as a liquid fertilizer. Crystalline ammonium thiosulphate contains 19% nitrogen and 43% sulphur and its aqueous solution contains 12% nitrogen and 26% sulphur.

Ammonium thiosulphate is compatible with nitrogen and nitrogen-potassium solutions, which are neutral or slightly acidic (pH 5.8). It is also used as a suspension. As it is non-corrosive, it can be stored in steel or aluminum drums.

Ammonium thiosulphate is prepared by the reaction of sulphur dioxide and aqueous ammonia, followed by a further reaction with elemental sulphur.



ATS can be applied directly to soils or as a foliar spray through sprinkler irrigation systems. When applied to soils, ATS decomposes into ammonium sulphate and colloidal sulphur. The ammonium sulphate is available immediately to plants, while the sulphur gets oxidized over a period of time to sulphate ion ( $\text{SO}_4^{2-}$ ). It is thus available to plants for a longer time.

Ammonium thiosulphate also acts as a urease inhibitor. When added to a urea-ammonium nitrate solution, it inhibits urease activity for a month or so. In industry, it is also used as a photographic fixing agent, analytical reagent, fungicide and as a brightener in silver-plating baths.

### Ammophos

Ammophos is the trade name of one of the most popular brands of ammonium phosphate fertilizers. It contains 16% nitrogen and 20% phosphorus (as  $\text{P}_2\text{O}_5$ ).

Ammophos is made by ammoniating a mixture of sulphuric and phosphoric acids. After ammoniation, the slurry formed is granulated in a pugmill or a drum unit, dried, and screened to give a product that is two-thirds by weight of ammonium sulphate and one-third that of ammonium phosphate. This water-soluble product has good storage properties.

Two grades of ammonium phosphate are known. One contains 11% nitrogen and 48% phosphorus (as  $\text{P}_2\text{O}_5$ ), the other contains 16.5% nitrogen and 20% phosphorus (as  $\text{P}_2\text{O}_5$ ). The first grade is made by neutralizing phosphoric acid with ammonia, and the other is made by neutralizing a mixture of phosphoric and sulphuric acids with ammonia. The first grade of ammophos has a theoretical lime requirement of 5 kg of calcium carbonate per kg of fertilizer, which indicates the acid forming nature of the fertilizer.

Ammonium dihydrogen phosphate sulphate is also called ammoniated sulphate. It is a double salt of ammonium dihydrogen phosphate,  $\text{NH}_4(\text{H}_2\text{PO}_4)$  and ammonium sulphate,  $(\text{NH}_4)_2\text{SO}_4$ , and is formed by neutralizing a mixture of sulphuric acid and phosphoric acid by gaseous ammonia.

### Amorphous humus

Amorphous humus is the dark-colored amorphous colloidal material in soil. It represents a complex fraction of organic matter of plant-animal-microbial origin that resists decomposition.

Amorphous humus, being a colloid, holds water, improves the water retaining properties of the soil and also enhances the soil workability and fertility.

**Humus** acts as a storehouse of elements which are important to plants and functions as a regulator of soil processes by gradually liberating the nutrients that would have otherwise drained away. A soil rich in humus provides optimum conditions for the development of beneficial micro-organisms and is the best medium for the growth of plants. (See also Humus.)

### Amorphous substances

Amorphous substances do not have their constituent basic particles (ions, atoms or molecules) regularly arranged as in crystalline materials. For instance, plasmas, gases and glasses are non-crystalline. Liquids are always in an amorphous state. In gases, the particles are so apart that they can exercise transitional, rotational and vibrational movements and form an assembly of statistically distributed particles. In liquids, the particles exhibit only short-range ordering.

The substances in an amorphous state are **isotropic** which means that their physical properties are the same in all directions.

Solids are subdivided into two categories – crystalline and amorphous. The amorphous solid is rigid and keeps its shape but does not exhibit a crystal structure or crystalline periodicity. Glasses, resins, some plastic substances and metallic glasses are examples of amorphous solids. According to some authors, such substances should be regarded as **super cooled liquids** with very high viscosity ( $> 10^{12}$  Pa S).

The obvious uses of amorphous solids include window glass, container glass and glassy polymers; the less recognized uses are as dielectrics and protective coatings in integrated circuits. In optical communications, amorphous solids are used in the form of fibres as a transmission medium.

The variation in the short-range order (and not necessarily the loss of long-range order alone) affects the properties of amorphous semiconductors. One class of amorphous semiconductors is the **glassy chalcogenides**, which contains one or more of the chalcogens – sulphur, selenium or tellurium – as major constituents. These materials have applications in switching and memory devices. Another group contains tetrahedrally bonded



amorphous solids, such as amorphous silicon or germanium.

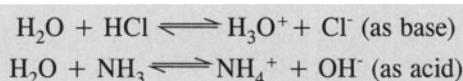
When amorphous silicon or germanium is prepared by evaporation, not all bonding requirements are satisfied. This necessitates a number of dangling bonds to be introduced into the material. These bonds create spaces deep in the gap, which limit transport properties. The thermal annealing below the crystallization temperatures can reduce the number of dangling bonds.

### AMP

AMP is short for **adenosine monophosphate**.

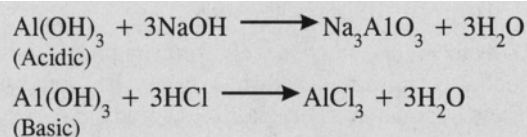
### Amphiprotic solvent

A solvent such as water that can donate and accept protons is known as an amphiprotic solvent.



### Amphoteric

Amphoteric is a compound that can act as both an acid and a base. For example, aluminum hydroxide (also the hydroxides of zinc, tin, lead) is amphoteric because it reacts as an acid with alkalis to give aluminates and also reacts as a base with acids to give salts.



Compounds like amino acids which have both acidic (COOH) and basic (NH<sub>2</sub>) groups in their molecules are amphoteric. Water, which can donate and accept protons, is known as an **amphiprotic solvent**.

The existence of amphoteric oxides is considered as evidence of the existence of metalloids.

### Amylase

Amylase is an enzyme that hydrolyzes starch. These enzymes, widely distributed in animals and plants, break down starch or glycogen to dextrin, maltose or glucose. Amylase in human saliva is called **ptyalin**.

### Amylopectin

Amylopectin is a **polysaccharide** consisting of various proportions of two glucose units joined by 1-4 linkages. The positions are where the two glucose units are linked to form the corresponding polymer. **Amylose** and amylopectin are examples of this polysaccharide. Amylopectin is less soluble in water and gives red or purple color with iodine.

### Amylose

Amylose is a type of **polysaccharide** and is a constituent of starch. Amylose is made up of linear links of several

hundred glucose molecules. A water-amylose mixture turns blue when iodine is added to it.

### Amylum

Amylum is an ordinary **starch**, that occurs in all green plants. It is a molecule of starch, built out of a large number of α-glucose rings joined by oxygen atoms, and is a major energy source for animals.

### Anabaena azollae

*Anabaena azollae* is a symbiotic cyanobacterium that colonizes the dorsal cavities of leaves of **Azolla**, a floating fern, and fixes atmospheric nitrogen.

**Anabaena-Azolla symbiosis** : See *Azolla-Anabaena* symbiosis

### Anaerobe

Micro-organisms that do not depend on the supply of free oxygen for respiration are called anaerobes. They are capable of living in the absence of free oxygen (gaseous or dissolved) and get the oxygen they need by reducing the oxygen-containing compounds in the soil.

There are two types of anaerobes (a) **obligate anaerobes** which grow only in the absence of oxygen, and (b) **facultative anaerobes** which can grow either in the absence or presence of oxygen. Anaerobes usually live in sewage water and biogas digester chambers.

### Anaerobic condition

Anaerobic condition is a reducing condition where no oxygen (or very little oxygen, either gaseous or dissolved) is available to organisms. In the absence of oxygen which is the most common electron acceptor, other substances like nitrate, ferric ion (Fe<sup>3+</sup>) and carbon act as electron acceptors. Thus, **bacteria** living under anaerobic conditions bring about denitrification wherein nitrate is converted to nitrogen.

In anaerobic conditions, growing plants produce 1-amino cyclopropane-1-carboxylic acid in their roots. These plants are intolerant to a waterlogging environment (poor oxygen transfers to the roots via stems). The acid is translocated to stems and petioles where oxygen is available and where it is quickly converted into ethylene. The presence of a high ethylene content in petioles causes the edges of the leaves to droop (**epinasty**). Leaf wilting may be due to a combination of (a) low water absorption by roots, (b) anaerobic conditions, or (c) water loss from leaves. Anaerobic conditions reduce the transport of growth hormones like gibberellic acid and abscisic acid.

Energy transformation in anaerobic conditions results in poor growth rates. Anaerobic conditions can also promote production of toxic substances like hydrogen sulphide, butyric acid and other volatile fatty acid components of carbohydrate decomposition. These toxins produced in the roots may be transported to the other parts of the plant.

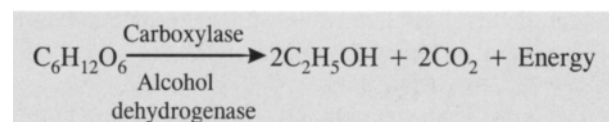


## Anaerobic decomposition

Anaerobic decomposition is the incomplete decomposition of organic matter by micro-organisms in an anaerobic environment. Compost, an example of anaerobic decomposition, is used as manure.

## Anaerobic respiration

Respiration that proceeds in the absence of oxygen is called anaerobic respiration. Some yeasts and bacteria perform anaerobic respiration. It is also called **intra-molecular respiration**.



## Anaerobiosis

Anaerobiosis is the generation of an anaerobic or oxygen deficient atmosphere. It has a significant effect from an agronomic or biological perspective.

## Analysis

Analysis, in general, means to separate something into its constituent parts to facilitate learning more about them. Chemical analysis of a material for instance, involves identification and measurement of the chemical constituents of the material.

There are different types of analyses, such as quantitative analysis, qualitative analysis, instrumental analysis and data analysis. Quantitative analysis involves the measurement of proportions of the components in a chemical mixture. Qualitative analysis determines the nature of pure unknown compounds or components in a mixture.

Qualitative analysis of a fertilizer gives the presence of different nutrients in it, while quantitative analysis gives the percentage composition of the nutrients in the fertilizer. Both chemical and instrumental methods are used in analyzing fertilizers. The analysis helps to designate the percentage composition of the fertilizer expressed in terms of the existing trade practice and law. For example, 28-28-0, indicates the percentage of N,P,K, respectively.

## Analysis of variance

Analysis of variance is a statistical method of comparing the averages of observations from different treatments (which include methods, factors, etc.), by comparing the variation among the means with the variation within the observations from the same treatment. If the former is significantly larger (as determined by the **F-test in statistics**) than the latter, the means are declared different and further analysis has to be carried out to determine which method is better. The F-test is also known as the **variance ratio test**.

## ANC

ANC is short for **acid neutralizing capacity**.

## Anchor roots

Anchor roots are adventitious roots that rise from the internodes to anchor the plant in order to render an upright position. Anchor roots are seen in many crops including corn roots.

## Andisols

Andisols are black or dark brown soils with weakly developed horizons, formed from volcanic ejecta as parent material. These form the A horizon which is rich in organic material.

As one among the 12 soil orders, andisols cover less than about 0.7% of the earth's ice-free surface. The parent material of andisols is mostly of volcanic origin and consists of volcanic ash, cinders, pumice and some basalt. Andisols, which exhibit a comparatively low bulk density, are a little more developed than entisols, while retaining the influence of volcanic ejecta.

After extensive **weathering**, andisols can change into another soil order. Rapid weathering is a dominant feature of most andisols which are physically, chemically and mineralogically unique. They are found along the tectonically active Pacific Ring of fire, Central Atlantic Ridge, North Atlantic rift, the Caribbean and the Mediterranean regions, where volcanic or pyroclastic deposits are common. These weakly developed fertile soils are texturally undifferentiated and are characterized by short-range order aluminosilicates not translocated from the upper to the lower horizons.

Andisols are used extensively for crop production in developing countries. Andisols have the following suborders: aquands, cryands, torrands, xerands, vitrands, ustands and udands.

## Ando

Ando, the former name for **inceptisols** in the USA, is a dark colored soil rich in organic matter developed in volcanic ash deposits. (See also Soil taxonomy.)

## Andrew's method of determining acidity or basicity

Andrew's method of determining acidity and basicity of nitrogenous fertilizers states that each kilogram of fertilizer nitrogen, as ammonia, requires 3.57 kg of chemically pure calcium carbonate for neutralizing the acidity when converted to the nitrate form. (See also Pierre method of determining acidity or basicity.)

## Angle of repose

The angle of repose is the angle that the sloping surface of a heap of loose material poured on a horizontal surface makes with the horizontal surface. The International Standardization Organization (ISO) defines it as the angle at the base of a cone of fertilizer formed with the vertical axis, as the material is allowed to fall onto a horizontal base plate under specified conditions.

The particle shape, size and surface texture of a fertilizer influence its angle of repose. Knowledge of the

angle of repose is necessary for the design of hoppers, chutes and conveyors that carry the fertilizer, and of the sloped roofs of fertilizer bulk storage buildings.

The ISO procedure for measuring the solid fertilizer static angle of repose (ISO 8398) involves pouring a sample through a funnel into a level base plate, measuring the diameter and height of the conical pile and calculating the base angle of the cone from these measurements (Fig.A.33).

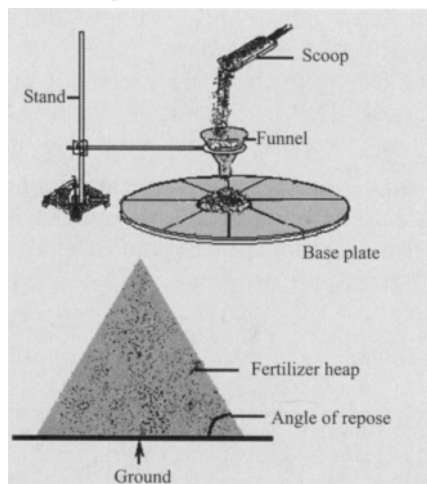


Fig.A.33: An apparatus for determining the angle of repose of fertilizers.

The values of the angle of repose for fertilizers normally range from about 25 to 40°. Spherical products like prilled urea, have a low angle of repose (<30°) and irregularly shaped products like granular KCl have a high angle of repose (>35°). Larger materials have higher angle of repose values than fine materials. In most rocks and sands, the angle of repose is 30 to 35°.

Angles of repose for different fertilizers are given in Table-A.6.

Table-A.6: Angles of repose for different fertilizers

Sr. No.	Name of fertilizer	Grade	Angle of repose
1.	Prilled urea	46-0-0	27-28
2.	Granular urea	46-0-0	34-38
3.	Granular ammonium sulphate	21-0-0	36-38
4.	Crystalline ammonium sulphate	21-0-0	29-36
5.	Prilled ammonium nitrate	34-0-0	29-38
6.	Granular diammonium phosphate	18-46-0	27-37
7.	Granular monoammonium phosphate	11-55-0	28-37
8.	Powdered monoammonium phosphate	10-50-0	30-34
9.	Granular triple superphosphate	0-46-0	28-35
10.	Granular potassium chloride	0-0-60	32-41
11.	Coarse potassium chloride	0-0-60	31-35
12.	Standard potassium chloride	0-0-60	28-32
13.	Granular potassium sulphate	0-0-50	28-35
14.	Phosphate rock (different sources)	-	30-35

Source: "Fertilizer Manual", 1998 UNIDO, IFDC and Kluwer Academic Publishers, The Netherlands. With permission.

## Angstrom

Angstrom, a basic unit of length, formerly used to measure wavelength and intermolecular distances, is named after a Swedish physicist, Anders J. Angstrom who studied the solar spectrum. Angstrom is not an S.I. unit and it has now been replaced by nanometer.  $1 \text{ \AA} = 0.1 \text{ nanometer}$ .

$$1 \text{ Angstrom (}\text{\AA}\text{)} = 1 \times 10^{-10} \text{ m} = 1 \times 10^{-8} \text{ cm.}$$

## Anhydrite

Anhydrite is a naturally occurring, solid, white mineral called anhydrous calcium sulphate ( $\text{CaSO}_4$ ). It differs from gypsum in hardness and in hydration. It is used as a raw material in the chemical industry and in the manufacture of fertilizers and cement.

## Anhydrous ammonia

Anhydrous ammonia is an ammonium fertilizer made by the **Haber-Bosch process**, by reacting hydrogen with nitrogen in the ratio of 3:1 at high temperatures (450 to 500°C) and pressure (about 500 atm) in the presence of an iron catalyst promoted by potassium and alumina. The nitrogen derived from air and the hydrogen obtained from (a) synthesis gas, (b) steam reforming of naphtha, coal or coke (c) lignite, or (d) electrolysis of water, are purified by standard procedures before use. The anhydrous ammonia thus produced can be directly used as a fertilizer. It can also be converted to ammonium salts which are important fertilizers, by reacting ammonia with nitric, sulphuric and phosphoric acids. Anhydrous ammonia is also reacted with carbon dioxide to get urea which is another important source of nitrogen.

Anhydrous ammonia is an important fluid fertilizer and is the cheapest nitrogen source, having the highest nitrogen content (about 82%) among nitrogenous fertilizers. However, because of safety and environmental considerations, many dealers and users are now switching over to other sources of nitrogen.

Anhydrous liquid ammonia can cause dehydration of tissue and severe damage to the skin, lungs and eyes by its freezing and caustic action. Because of the low vapor pressure (6 bar at 10°C, 9 bar at 20°C and 12 bar at

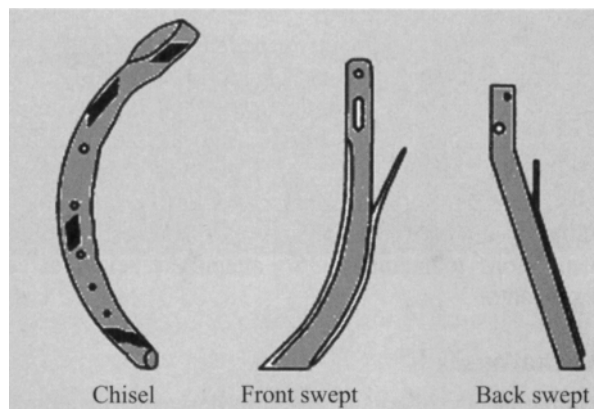


Fig.A.34: Tools used in the application of anhydrous ammonia.

30°C), anhydrous ammonia must be stored and transported in pressure vessels.

Due to the volatile nature of anhydrous ammonia it has to be injected with an applicator 15 to 30 cm below the soil surface to be effective and to reduce ammonia loss (Fig. A.34). Ammonia loss depends on the soil type, its moisture content, and the depth to which the applicator is injected (Fig. A.35).

Ammonia applicators range in size from small 5-row rigs to large rigs that have a swath width of upto 20 m (65 feet) and are pulled by high-powered tractors. Anhydrous ammonia is usually metered by a variable orifice-type meter or by a piston pump.

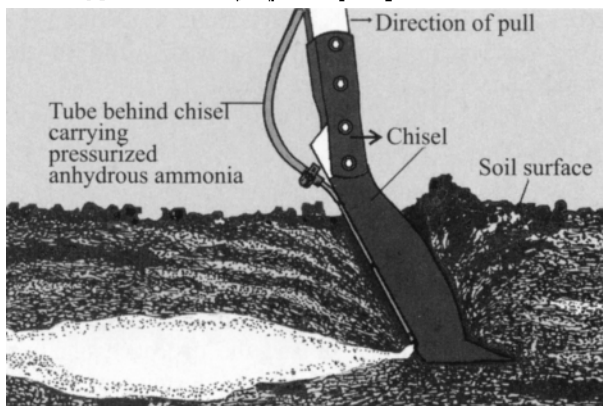


Fig. A.35: Anhydrous ammonia gas released in the soil under pressure (behind the chisel) at a depth of about 15cm gets adsorbed on soil particles.

Physical properties of anhydrous ammonia are somewhat similar to other liquids under pressure like butane or propane gas. Because of the difficulties in handling anhydrous ammonia, water solutions of ammonia, urea, ammonium phosphate or other soluble solid nitrogen materials are used widely. Anhydrous ammonia is also used in the preparation of protein feeds for cattle and sheep, and as a defoliant to hasten the shedding of cotton leaves to facilitate mechanical harvesting.

### Anhydrous ammonia sulphur

The sulphur compound in N/P/-S fertilizer reacts with nitrogen to provide 5 to 20% sulphur to the fertilizer. This sulphur, being an integral part of the fertilizer, may be oxidized more rapidly than when it is added separately. Thus, sulphur is added (up to 10%) to anhydrous ammonia to provide sulphur and nitrogen to growing plants. This compound is called anhydrous ammonia sulphur. When injected into the soil, most of the sulphur separates and is oxidized slowly to sulphate ion. The other sulphur containing fertilizers are urea-sulphur, sulphur fortified superphosphate and sulphur suspensions containing 3% attapulgite clay as a flocculent.

### Animal meals

Animal meals are organic manures derived from animal wastes or by-products at butcher shops, slaughterhouses and carcass disposal plants. These include horn meal,

bone meal, blood meal, hide meal, feather meal, meat, and carcass meal.

**Horn meal** (horns, hoofs, claws, etc.) consists mainly of protein and keratin which decomposes slowly. The main constituent of **bone meal** is protein collagen, which is extracted by hot water and steam, and applied mainly as a phosphate fertilizer. **Blood meal** often contains other slaughterhouse wastes such as intestine contents and has a short-term effect on nitrogen supply. The main constituents of **hide meal** are skins and hair, where the effect of the nitrogen supply is quite slow. Sometimes, it is contaminated with toxic chromium salts. **Feather meal**, like horn meal is a slow nitrogen-releasing fertilizer with nitrogen content of around 13%.

Meat and carcass meals are short-term nitrogen suppliers and are converted into organic fertilizers because they contain a high proportion of protein. Table-A.7 gives nutrient contents of some animal waste-based manures.

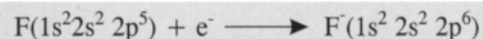
Table-A.7: Nutrient contents (% dry matter) in animal waste-based manures

Nutrient content	Horn meal	Blood meal	Feather meal	Bone meal	Carcass meal
N	10-14	9-13	12	4-6	6-11
P	0.4-4.0	0.2-1.0	0.3	7-12	2.4-7.0
K	0.2-0.8	0.2-1.5	0.2	0.2	0.3-0.5
Ca	1.5-7.5	1.5-3.0	-	18-25	4-10
Mg	0.5-1.0	0.4	-	0.6	0.2
C/N	3-4	2.4	4	4.5	3.5

Source: "Agrochemicals", 2000, Edited by Franz Muller. Wiley-VCH Verlag GmbH & Co. KGaA. Reproduced with permission.

### Anion

An anion is an atom which gains or acquires an electron, becomes negatively charged, and is attracted toward the anode in electrolysis. Thus, a fluorine atom, by taking up an electron in its p orbital, becomes a fluorine ion (fluoride ion).



Anions are generally drawn from an atom of a non-metal like fluorine (F) or a group of atoms (for example,  $SO_4^{2-}$ ). The number of electronic charges carried by the anion is called its **electrovalence**.

Salts are usually composed of orderly arrangements of ions which are not free to move easily in a solid. However, when a salt is fused or dissolved in water, the ions become free. When an electric field is applied to the solution, the positively charged ions move to the cathode while the negatively charged ones move to the anode. These ions, upon reaching the electrodes, lose their charge.

### Anion adsorption

Both inorganic and organic anions can compete with phosphorus for adsorption sites, resulting in decreased

adsorption of the added phosphorus. The strength of bonding with the mineral surface determines the competitive ability of that anion. Generally, weakly held inorganic anions such as  $\text{NO}_3^-$  and  $\text{Cl}^-$  are of little consequence, whereas specifically adsorbed anions such as  $\text{OH}^-$ ,  $\text{SO}_4^{2-}$  and  $\text{MoO}_4^{2-}$  can be competitive with phosphorus adsorption ( $\text{H}_2\text{PO}_4^-$ ).

Anion adsorption of small cations occurs by surface complexation and by diffuse-ion swarm association. The outer-sphere surface complexation of anions entails coordination to a protonated hydroxyl or amino group or to a surface of metal cation. The anions  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SeO}_4^{2-}$ , and to a lesser extent  $\text{HS}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$ , are reckoned to adsorb mainly as diffuse-ion swarm and outer-sphere complex species.

### Anion exchange

Anion exchange is the exchange or replacement of one anion by another on the positively charged exchange complex. The exchange of ions of the same charge takes place between a solution (usually aqueous) and a solid (ion exchange resin) in contact with it. The type of exchange, whether cation or anion, is determined by functional groups added to the resin. **Ion exchange resins** are ideally suited to protein purification, antibody isolation and peptide fractionation. They are also used in a traditional inorganic ion exchange. **Anion exchange resins** have ammonium ions in the framework of the resin as the ion exchange site. **Cation exchange resins** have sulphonic or carboxylic acid groups as the exchange site.

An anion exchange resin is used in softening water. When water is passed through anion exchange resins, the electronegative ions present in water (like  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ) are held by the ammonium ions in the resin. The outgoing water is devoid of electronegative ions, and, if subsequently passed through a cation exchange resin, the water practically contains no ions and can be used in place of distilled water. Treating with moderately concentrated solution of caustic soda can regenerate the resin.

The reaction processes in resins occur widely in nature, especially in the absorption and retention of water-soluble fertilizers by soil. The order of adsorption of anions is  $\text{H}_2\text{PO}_4^- > \text{SO}_4^{2-} > \text{NO}_3^- = \text{Cl}^-$

### Anion exchange capacity

The anion exchange capacity (AEC) of a soil is defined as its capacity to hold or adsorb anions in an exchangeable form to the positively charged sites on clay minerals and organic matter. AEC, expressed as milliequivalents/100 g soil, is an indicator of the positive charge (or the positively charged sites) on clay minerals and organic matter in the soil.

Anion exchange capacity increases as the soil pH decreases. Anion exchange is much greater in soils high in 1:1 clays and soils containing hydrous oxides of iron and aluminum than it is in soils predominantly having 2:1 clays. **Montmorillonite** clay minerals have an anion exchange capacity of less than 5 meq/100 g, while

kaolinites can have an anion exchange capacity as high as 43 meq/100 g at pH 4.7.

### Anion exchange resin

Anion exchange resin is another term for anion resin.

### Anionic resins

Anionic resins or **anion-exchange resins** possess a positive charge on the functional group. During an ion exchange reaction, anions such as  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{OH}^-$  are exchanged. A polyaniline based anionic resin is given in Fig. A.36.

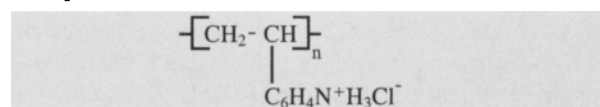


Fig.A.36: Polyaniline based anionic resin.

### Anionic surfactant

An anionic surfactant is a type of ionic surfactant used for coating fertilizer materials to improve fertilizer quality. Commonly employed anionic surfactants are sulphonates, particularly alkyl aryl sulphonates, and their action is due primarily to their hydrophobic nature. Sodium stearate ( $\text{C}_{17}\text{H}_{35}\text{COO}^-\text{Na}^+$ ) is an example of an anionic surfactant. (See also Adjuvant; Anti-caking agents.)

### Ankur

Ankur is an aqueous solution of urea (33.5 to 36.0%) and ammonium nitrate (44.5%) with 1% corrosion inhibitor. Ankur is used as a nitrogenous fertilizer (like urea-ammonium nitrate).

### ANL

ANL is short for **ammonium nitrate limestone**.

### ANL brand fertilizer

ANL is the trade name for a fertilizer which is a mixture of ammonium nitrate (AN) and lime or pulverized dolomite. ANL is manufactured at Hopewell, Virginia, in the USA. When added to the soil, it reduces the hazardous characteristics of AN.

ANL fertilizer contains 20% nitrogen, 10% calcium oxide (CaO) and 7% magnesium oxide (MgO). It is hygroscopic and is protected from atmospheric moisture during storage and transportation by coating the pellets with soapstone (sodium silicate).

### Anne method for determining organic carbon

Anne method is one of the two methods for determining organic carbon in the soil. In this method, the organic matter is attacked and destroyed by boiling it slowly in an excess mixture of sulphuric acid and potassium dichromate. The excess potassium dichromate is determined by Mohr's salt ( $\text{FeSO}_4$ ) in the presence of diphenylamine as indicator. The results obtained from this method match well with those obtained from the dry method. This method can also be used to analyze plant materials. (See also Walkley-Black method.)

### Annual

An annual is a plant that completes its life cycle in one year or less, during which it germinates, flowers, produces seeds and dies. Most cultivated crops like grain, fodder, pulse crops, some oilseed crops (other than coconut, oil palms, etc.) Sunflower, wheat, rice and marigold are examples of annuals (Fig. A.37). **Winter annuals** refer to plants that complete their life cycle during the winter season. Ornamental plants like dahlia and carnations are winter annuals.

### Annual ring

Annual ring is the ring that can be seen in a cross section of a trunk in trees. It represents the xylem formed in one year by the fluctuating activity of vascular cambium. The **age of the tree** can be determined by counting the number of cross sectional rings. The study of annual rings is known as dendrochronology.

### Annual soil temperature

The annual average temperature of a soil is considered the annual soil temperature. 'Standard' soil temperature is normally measured at the rock or hard-pan, or at a depth of 50 cm unless the soil is 50 cm deep. Average annual soil temperature (AST) is measured at a depth of approximately 90 cm or 180 cm. The temperature values recorded at both the depths are usually very close. The difference between the warmest and the coldest monthly means of temperature is known as annual temperature range (of the soil).

### Anorthite

Anorthite is one of the four components of feldspars, expressed as  $\text{CaAl}_2\text{Si}_2\text{O}_8$ . **Feldspars** are a group of

silicate materials. They are the most abundant minerals in the earth's crust. Anorthite or **pure calcium feldspar** belongs to the plagioclase subdivision of feldspars.

### Anoxia

Anoxia represents a condition where oxygen is absent. Waterlogged soils create anoxic conditions in which the decomposition of organic matter slows down. In bogs and swamps, for instance, the rate of decomposition is so low that plant remains are preserved for many years. A few micro-organisms prefer anoxic conditions for their growth. *Clostridium* sp, yeasts, etc. are examples.

### ANR

ANR is short for **apparent nutrient recovery**.

### Antagonistic interaction

Antagonistic interaction or **negative interaction** is a phenomenon where the combined effect of two or more nutrients is lesser than the effect of each of these nutrients, taken separately.

When the presence of a nutrient adversely affects the absorption of another nutrient, the two nutrients are said to interact antagonistically. For example, excess copper affects iron nutrition, or excess amounts of potassium and calcium depress the absorption of boron.

While synergistic effect attracts attention, the antagonistic effect between nutrients is often ignored. What is important is to know (a) the situation when two or more nutrients result in antagonistic effect, and (b) the range over which the change-over takes place from synergism to antagonism and vice versa. This would help in balancing plant nutrients which are considered antagonistic pairs.



Fig.A.37: Sunflower, a major oil seed crop is an annual crop.

### Anthracite coal

Anthracite coal is a hard and black variety of coal, with a fixed carbon content in the range of 80 to 98% and a heating value of  $14243 \times 10^3$  to  $16458 \times 10^3$  J.

### Anthropic

Anthropic or **anthropic horizon**, is a surface horizon (or epipedon), with high basic cation saturation created by human activities such as cultivation or construction. When the cause is agricultural activities, it is called cultivated horizon or **agropedic horizon**. In this, the surface horizon is homogenized by plowing or other means. In terms of color, thickness and organic matter, it has the same appearance and characteristics as mollic epipedon. The change occurring in the soil due to human activity (like plowing, fertilizing or construction) is called **anthropogenic change** or **anthropic change**.

**Anthropic change:** See Anthropic

**Anthropic horizon:** See Anthropic

**Anthropogenic change:** See Anthropic

### Antiauxin

**Auxins** are plant growth promoting substances, responsible for many growth processes. Antiauxins by contrast, compete with auxins for specific receptors.

Antiauxins inhibit the transport of auxins in the plant and thus affect plant growth and morphology. An example of an antiauxin is maleic hydrazide.

### Anti-caking agent

Anti-caking agents are materials used for the surface treatment of granular fertilizers to prevent caking.

An anti-caking agent helps maintain the physical condition (such as easy-flow characteristics, storage and handling) of a fertilizer.

Anti-caking substances are categorized as coating agents (which consist of inert powders and liquid coating agents) and internal conditioners. The two categories are described below.

(i) **Coating agents:** These are **conditioning materials** applied uniformly onto fertilizer particles. Most coating agents are either very finely divided inert powders (which adhere to particle surfaces) or liquid coating agents that are sprayed onto the surface.

**Inert powders**, like clays (kaolin and china), diatomaceous earth (kieselghur) and **talc** (basic magnesium silicate) form mechanical barriers between the material particles and also serve to absorb, spread and inactivate any solution phase that may occur on the particle surfaces. During caking, bonding occurs between the particles; the dust-type anti-caking agent weakens the bonds and reduces the severity of caking.

Inert clay powders are extremely fine (typically, 90%

are less than 10 mm, 50% of which are less than 1 mm), adhere well to fertilizer granules and are used effectively on urea, NP and NPK complex fertilizers, but not on ammonium nitrate or other high nitrate products. Diatomaceous earth does not adhere well as does clay, but it has a good absorption property and is an effective anti-caking agent for ammonium nitrate. Major disadvantages of inert powders as anti-caking agents are their dustiness and diluting effect on the main nutrient element.

Inert powders can be made to adhere better by spraying the fertilizer with a small amount of oil or wax-free binders (usually 0.1 to 0.3%). Fairly viscous oils (25 to 200 MPa) give maximum results.

**Liquid coating agents** are organic surfactants or non-surfactants. They usually function as crystal modifiers to inhibit or weaken the crystal growth on and between the particles, or as hydrophobic barriers to moisture absorption.

Surfactants function by altering the interfacial tension between the solid (particles) and the liquid (surfactant). Their role as anti-caking agents is not clearly understood, but they are believed to (a) provide protection from moisture, (b) spread the liquid film, (c) change crystal make-up or behaviour, (d) inhibit dissolution and crystallization, or (e) modify bond tensile strength.

Surfactants are both ionic and non-ionic. **Ionic surfactants** are those that contain either cationic or anionic molecules or groups in their structure. The commonly employed **anionic surfactants** are sulphonates, particularly alkyl aryl sulphonates, and their action is due primarily to their hydrophobic nature. **Cationic surfactants** are fatty amines, which act by three different mechanisms (a) forming a hydrophobic coating on the surface of the particles, thereby improving water repellence, (b) reducing the capillary adhesion between the particles, and (c) inhibiting nucleation or modifying crystal growth.

**Non-ionic surfactants** are neutral surfactants that do not ionize in water and do not form positively or negatively charged ions. They are non-toxic and are unaffected by hard water. Non-ionic surfactants, like polyoxyethylene condensates, are poor anti-caking agents and not widely used. Silicone fluids belong to this category.

Non surface-active coating agents are organic compounds. They do not exhibit surface activity but do form a moisture-resistant layer on the surface of the fertilizer particles. Typical non-surface active coating agents include paraffin wax, synthetic polymers and oils.

(ii) **Internal or chemical conditioners:** These conditioners are added to fertilizers during processing, usually as hardeners or crystal modifiers, to improve storage properties.

For urea conditioning, the following composition is found effective: Molten urea 0.3 to 0.5% of 37% formaldehyde solution or concentrated urea



formaldehyde (containing 26% urea, 59% formaldehyde, 15% water). This reduces the formation of dust in the finishing process because the granules are harder and more resistant to abrasion and breakage than untreated ones.

For ammonium nitrate, the most popular internal conditioner is magnesium nitrate (1.8% magnesium nitrate).

### Anticlines

Sedimentary rock layers that are folded into arch shapes are known as anticlines. (See also Fold.)

### Antifloat materials

Antifloat materials (like diatomaceous earth) or wetting agents (like liquid surfactants) are the coatings applied to the external surface of a fertilizer to achieve an antifloat effect by breaking the surface tension between water and the coated fertilizer. Special controlled-release fertilizers sink immediately on application and are applied to irrigated crops. **Polyon PCU-AF/Antifloat**, marketed by Sumitomo in Japan and **Multicote**, a resin-coated antifloating urea, are examples of the special controlled-release fertilizer class.

### Anti-transpirants

Anti-transpirants are substances that retard the transpiration rate of plants, mainly by affecting the size of the stomatal opening. Monomethyl ester decenyl succinic acid is an example of an anti-transpirant.

### AOV

AOV is the abbreviation for **analysis of variance**. (See also Variance.)

### Apatite

Apatite is a highly complex hexagonal structured mineral form of calcium phosphate  $[Ca_5(PO_4)_3(OH, F, Cl)]_2$ . It is the most common of all phosphate minerals. Depending upon the dominance of fluorine, chlorine or hydroxide, apatite is called **fluorapatite**, chlorapatite or **hydroxyapatite**, respectively.

Apatite often occurs widely as an accessory mineral with igneous rocks, such as pegmatite. It also occurs in regional and contact metamorphic rock, especially limestone. Large deposits of apatite are found in Russia.

Apatite, a major source of phosphorus, is used in the production of fertilizers. Enamel of the teeth is composed chiefly of apatite.

### Apical meristem

Meristem is the portion of cells of a plant tissue, found mainly at the growing tips of roots and shoots and in the cambium. Meristems are composed of actively dividing cells which form a new tissue.

Apical meristems (Fig.A.38), the most important meristems, are regions at the tips of each shoot and root of a plant in which cell division occurs continually to produce new stem and root tissues. The new tissues produced are known as the primary tissues of the plant. (See also Meristem.)

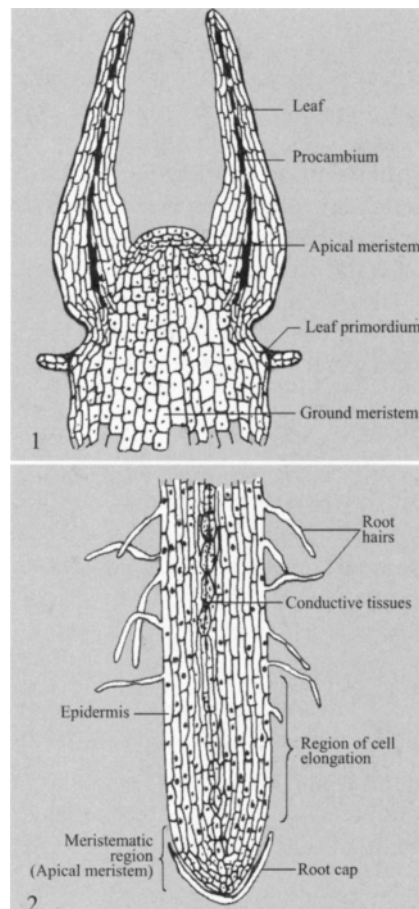


Fig.A.38: Diagrammatic representation of the longitudinal section of shoot (1) and root showing regions of apical meristem (2).

### APN

APN is short for **ammonium phosphate nitrate**.

### Apocarpous

Apocarpous are flowers that have many separate carpels, *Michelia* as an example.

### Apoplast

Apoplasts are interconnected cell walls or extra-cellular spaces. The system of interconnected cell walls is a pathway of solute (water and dissolved mineral salts) movement across the cortex that leads to the stele in a plant system.

### APP

APP is short for **ammonium polyphosphate**.

### Apparent bulk density

Apparent bulk density (or the **apparent density**) of a fertilizer, is the mass per unit volume of a fertilizer



excluding voids between the particles. It is not often measured but is of interest in particle segregation studies and in the development of granulation processes. In the case of fertilizers, it is measured by using a bulk density box or bulk density cup. (See also Bulk density of fertilizer.)

**Apparent density:** See Apparent bulk density

### Apparent free space

Apparent free space refers to the hypothetical partial volume of a tissue through which a solution can pass passively. It becomes a true measure of the free space only if the test solute concentration in the free space is the same as that in the external solution with which the plant tissue has equilibrated. When the solute concentration is higher in the free space than in the external solution under high transpiration conditions, the apparent free space value is also high.

Apparent free space is also that fraction of the root volume into which the external solution appears to diffuse.

### Apparent nutrient recovery

Apparent nutrient recovery (ANR) is defined as the nutrient absorbed by a crop from a fertilizer and is expressed as a percentage of the nutrient applied. ANR tends to overestimate fertilizer recovery and is generally measurable without resorting to a tracer technique.

ANR is defined as follows:

$$\text{ANR} = \frac{\left[ \begin{array}{c} \text{Nutrients removed} \\ \text{from fertilized plot} \end{array} \right] - \left[ \begin{array}{c} \text{Nutrients removed} \\ \text{from unfertilized plot} \end{array} \right]}{\text{Nutrient added}} \times 100$$

### Apparent recovery efficiency

Apparent recovery efficiency is the same as **apparent nutrient recovery**.

### Application of fertilizer

Fertilizer application refers to the act of applying or administering fertilizers, manures or amendments to crops on fields, grasslands, forests or any type of soils. There exist several methods for applying fertilizers. Some of these are **surface banding, strip (dribble) banding, deep banding, high-pressure injection, broadcasting, side dressing** and **foliar spray**.

### Aprotic solvent

Aprotic solvent is a solvent which neither donates nor accepts protons. Carbon tetrachloride is an example of an aprotic solvent.

### APS

APS is short for **ammonium phosphate sulphate**.

### AQ

AQ, also called **acidity quotient**, is the exchange acidity ratio of litter, given by the ratio of exchange acidity of **humus** to that of the top horizon. It characterizes the influence of humus on soils. An AQ of less than one indicates a healthy soil.

The characteristics of humus fractions are useful in interpreting organic matter dynamics. Carbon to nitrogen to phosphorus ratios in humic acid (HA) and fulvic acid (FA) fractions help to assess the origin and the turnover of nutrients in the soil organic matter from different depths and zones. HA to FA ratios are frequently used as indices of the degree of humification in soil. These ratios are believed to reflect intense humification caused by biological activity.

### Aqua ammonia

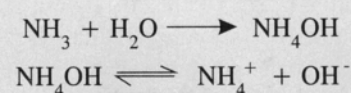
Aqua ammonia, also called **aqueous ammonia**, **ammonia liquor** and **ammonium hydroxide** is ammonia dissolved in water to form a clear, colorless liquid with a pungent odor. It is the simplest nitrogen solution made by forcing compressed NH<sub>3</sub> (anhydrous ammonia) gas into water. It has a pressure of less than 0.7 kg/cm<sup>2</sup> and is usually composed of 25 to 29.4% ammonia by weight (20 to 25% nitrogen).

Ammonia dissolved in water is present principally as the ammonium ion (NH<sub>4</sub><sup>+</sup>). Non-ionized molecular ammonium hydroxide (NH<sub>4</sub>OH), sometimes referred to as an **associated form of ammonium hydroxide**, is also present. Hydrated molecules of ammonia (NH<sub>3</sub>) may also exist as NH<sub>3</sub>·H<sub>2</sub>O or NH<sub>3</sub>·2H<sub>2</sub>O.

Purified water is used for the reaction of ammonia and water in the production process. The methods for water purification are (a) a conventional sodium-form water-softening ion exchange resin, which replaces all cations present with sodium ions, (b) both hydrogen-form cation resin and hydroxyl-form anion resin, resulting in total de-ionisation of water, or (c) reverse osmosis purification equipment which results in total de-ionization of water.

If water hardness is sufficiently low and/or if suitable filtration is available to remove the precipitate formed during the reaction of ammonia with water, the product can be manufactured without pre-treatment of water. For most water supplies, the precipitate is principally calcium carbonate.

During the reaction of ammonia with water, a large amount of heat is generated, which requires heat exchangers to control the temperature. The resulting aqua ammonia contains ammonium ions (NH<sub>4</sub><sup>+</sup>), hydroxyl ions (OH<sup>-</sup>), and non-ionized ammonium hydroxide molecules (NH<sub>4</sub>OH). The chemical reactions are:



The grade or strength of ammonium hydroxide available commercially is 26 degree Baumé. The Baumé reading refers to a specific gravity scale. A 26 degree Baumé (Bé) solution is equivalent to 29.4% by weight of ammonia dissolved in water. Since the Baumé reading varies with temperature, the reading is standardized at minus 9.4°C. The density of the material compared to water is 0.8974. Ammonia products of 29.4% strength are also frequently described as **26° Bé products**, the freezing point of which is about minus 62.2°C.

An aqueous solution has a vapor pressure which varies with temperature. At ambient temperatures, the vapor pressure of 26° Bé material equals atmospheric pressure. This permits the material to be shipped and stored in non-pressurized containers. This is the highest strength material generally available commercially.

Aqua ammonia should be stored in a closed container and kept cool, as otherwise the ammonia gas comes out of the solution and the strength reduces. The nitrogen concentration in aqua ammonia can be increased to 40% by partial pressurization.

Aqua ammonia is corrosive to copper, copper alloys, aluminum alloys and galvanized surfaces. Aqua ammonia is an excellent acid neutralizer. Its pH varies with concentration; typical values of pH are 11.7 at 1%, 12.2 at 5%, 12.4 at 10% and 13.5 at 30% concentration.

Transport and delivery costs limit the production of aqua ammonia (NH<sub>3</sub>) to small, local, fluid fertilizer plants. Aqua ammonia is regularly available in concentrations of 19%, 25% and 29%. These are used for direct soil application or as inputs to produce other liquid fertilizers. Ammonia volatilizes quickly at temperatures above 10°C; therefore, aqua ammonia is usually injected into soil to depths of 5 to 10 cm. It should not be used in calcareous soil.

### Aqua-gels

Polyacrylates, a form of polymers, are also known as aqua-gel. They are used alone or with starch to promote water storage in soils. The water holding effect, however, varies with pH, water hardness and such dissolved substances as urine or soil nutrients.

Polymer dispersions are employed to protect seeds. They are applied at planting time by spraying, usually along with fertilizers, soil conditioners and mulches (cellulose, straw). They can also be applied after planting. The quantities used depend on the actual formulation, and vary between 10 and 50 g/m<sup>2</sup>. Polymer dispersion products may be diluted in a product to water ratio of 1:1 to as much as 1:60. The protective action of polymer dispersions depends upon the quantity used and environmental conditions.

### Aqualfs

Aqualfs are a suborder of **Alfisols**.

### Aquands

Aquands are a suborder of **Andisols**.

### Aqua regia

Aqua regia is an extremely effective oxidizing solvent, capable of dissolving metals like gold and platinum. It is made of a mixture of one part concentrated nitric acid and three parts hydrochloric acid.

### Aquents

Aquents is a suborder of **Entisols**.

### Aqueous ammonia

When ammonia is dissolved in water, it forms aqueous ammonia. Aqueous ammonia is also called **aqua ammonia**, **ammonia liquor** or **ammonium hydroxide**. It is a clear, colorless liquid with a pungent odor. It is the simplest nitrogen solution, made by forcing compressed anhydrous ammonia gas into water. It has a pressure of less than 0.7 kg/cm<sup>2</sup> (10 lb/in<sup>2</sup>) and is usually composed of 25 to 29.4% ammonia by weight (20 to 25% nitrogen).

### Aquerts

Aquerts is a suborder of **Vertisols**.

### Aquic condition

Aquic condition is a condition brought about when soil remains excessively wet for a large part of the year. Aquic condition is caused by the saturation of soil by a fluctuating water table or by the presence of water on the capillary fringe of the water table. It is a reducing medium.

### Aquic soil moisture regime

Aquic soil moisture regime is the soil that is saturated with water and depleted of oxygen. Low chroma mottles are indicative of this condition. (See also Wetlands.)

### Aquolls

Aquolls is a suborder of **Mollisols**.

### Aquults

Aquults is a suborder of **Ultisols**.

### Arable farming

The system in which a land is plowed and sown, once or more than once a year is called arable farming. In this way, it contrasts with pasture lands. Arable farming is commonly practiced.

### Arable land

Arable land or **arable layer** is the land fit for tillage or plowing at regular intervals. In a cultivated soil, the arable land may resemble the Ap horizon. In most **rendzinas**, arable land nearly coincides with the pedological profile.

**Arable layer:** See Arable land

### Arborio rice

Rice is classified on the basis of the grain variety. Many famous varieties of rice include California Moish rice, Thai Jasmine rice, Indian rice, black rice (China), etc. Arborio is a rice variety common to Italy. Since it absorbs water or liquid five times its weight, it cooks into a creamy consistency. This rice is white, starchy and round with a distinctly firm center. The rice has a medium length and it is common in risotto dishes.

### Arbutoid mycorrhizae

Arbutoid mycorrhizae are the transition stage between ectomycorrhizae and endomycorrhizae. A fungal sheath on the roots of the host plant characterizes these mycorrhizae. Plants show the greatest growth response to mycorrhizae in highly weathered tropical soils, like the leached **oxisols** and **ultisols**. These soils are acidic, low in basic cations, low in phosphorus and may have a high toxic level of aluminum. (See also Mycorrhizae.)

### Archebacteria

Archebacteria is a subgroup of bacteria, comprising **methanogens** and species capable of tolerating extremely high temperatures or a salty environment.

### Arenaceous

Soils that have a high proportion of sand particles are considered arenaceous. For instance, sandstone is an arenaceous rock. Arenaceous rock is a sedimentary rock composed mainly of cemented grains of sand.

### Arenic horizon

Arenic horizon designates an extra grade subgroup characterized by a sandy epipedon 50 to 100 cm thick over an **argillic horizon**.

### Arents

Arents are a suborder of **Entisols**.

### Argids

Argids are a suborder of **Aridisols**.

### Argillaceous soils

Argillaceous soils are clayey soils having a high percentage of clay particles. Mudstone and marl are the examples of argillaceous soils.

### Argillan

Argillan is the layer or coating of clay on the surface of soil peds, mineral grains and soil pores. The coatings are classified according to the type of surface, such as grain, aggregate, channel, crack, normal void and chamber vesicle. The argillan coating is also called **clay films**, **clay shins** or **cutans**.

### Argillic horizon

Argillic horizon is the clay accumulation horizon

indicated by the letters 'Bt'. It is formed below the soil surface and is a mineral horizon characterized by the accumulation of illuvial clay and covered by an eluvial horizon.

The argillic horizon must have a certain thickness which is related to the thickness of the solum. The clay content of the argillic horizon must be higher than that of the eluvial horizon. For example, if the **E horizon** contains 10% clay, the argillic horizon must contain at least 13%; if the former contains 20% clay, the argillic horizon must contain at least 24% clay coating as observed on pore walls, structural units or between the sand grains. The clay is seen in the form of clay films on ped faces, and is also observed on pore walls, structural units or between sand faces.

The argillic horizon can be subdivided into subtypes, which are distinguished by some characteristic features and properties. These subtypes are identified by the following prefixes to the word argillic: **abrupto**, **ferro**, **fibero**, **fragio**, **grano**, **lixo**, **luvo**, **natro**, **neo**, **nito**, **ortho**, **plano**, **pleintho**, **retro** and **stagno**.

### Arid land

Arid land is a dry and parched land, often with sparse vegetation, and characterized by deficient rainfall (< 250 mm.) The term is often used to describe a region with insufficient rains to support vegetation without irrigation. In arid regions, droughts are very common because of extremely low rainfall. Estimates of the arid climatic zone vary from 15% to 30% of the world's land surface, depending upon the strict definition of arid climate.

**Aridic moisture regime:** See Aridic regime

### Aridic regime

Aridic regime or **aridic moisture regime** is an area with less moisture and high temperature. All parts of the soil moisture control section of aridic regime are dry. Soil temperature at 50 cm depth is above 5°C for more than six months in a year and the soil is never moist for 90 consecutive days in a year. Soils with an aridic regime are mostly found in zones of arid climate and sometimes semi-arid climate.

Aridic and **torric** are synonymous but used in different legends of classification.

### Aridisols

Aridisols are one of the 12 soil orders of the world. They develop in a climate with long dry periods and a few wet spells. These soils have a low water retention capacity. Aridisols occur mostly in hot, temperate or sub-temperate deserts with aridic soil moisture regimes, dry coastal regions, rain shadow plains, and on the leeward side of high mountains.

Aridisols cover about 12% of the ice-free land area of the world, and show a variety of profiles. Some have a

lime layer, some others have salt accumulation, and yet others have thick carbonate silica-cemented hardpans. Aridisols range from bare rich to bare poor soils and exhibit a wide diversity in physical, chemical and mineralogical properties.

With clay accumulation, aridisols develop argillic horizons (Bt horizon). Aridity restricts vegetation in such soils and lowers their organic content. Similarly, the lack of water in the soil reduces leaching and increases the basic cation saturation. In some aridisols, leaching is shallow with no salt accumulation. The vegetative cover of aridisols is desert shrubbery and short grasses. Aridisols in cold climates, however, have a different vegetation from that in warmer climates.

Aridisols need irrigation for crop production. They often become productive with the addition of water and fertilizer.

Aridisols are nitrogen deficient because of low humus content. They are also deficient in iron, zinc, manganese and copper. However, reduced leaching causes accumulation of potassium; potassium deficiency is, therefore, rare.

The suborders of soils belonging to aridisols are argids and orthids.

### Aridity index

Aridity index (AI) is a measure of dryness of an ecoregion. It is defined as the ratio of annual moisture deficiency to annual water needs.

$$AI = \frac{\text{Number of rainy days} \times \text{Mean precipitation per day}}{\text{Mean temperature} + 10}$$

Aridity index is a measure of the effectiveness of the precipitation received. It could be described as a measure of evaporation. Death Valley in California (USA) has an aridity index of 7, which means the sun would evaporate seven times the average rainfall received. On the other hand, the Sahara has an aridity index of 200, meaning 200 times the average rainfall would be evaporated.

Moisture deficiency or aridity index is used to define drought. Drought intensities using standard deviation (s) of aridity index to analyze the occurrence of droughts in arid zone ecologies are defined in Table-A.8.

Table-A.8: Relationship between aridity index and drought.

Departure of aridity index from normal	Result
< ½s	Moderate
½s to 1s	Large
1s to 2s	Severe
> 2s	Disastrous

Source: "Introduction to Tropical Agriculture", Edited by Anthony Youdeowei, et al. Longman Scientific and Technical, Longman Group, UK, Ltd. With permission from Pearson Education Ltd.

### Arnon's criteria of essentiality of plant nutrients

Arnon and Stout proposed three criteria that are now used to decide if a plant needs nutrients. They are also called the Stout-Arnon's criteria of essentiality of plant nutrients.

Essentiality criteria are that (a) the deficiency of an element results in a plant completing its life cycle, (b) the deficiency is specific to the element in question and (c) the element is directly involved in the nutrition of the plant, such as a constituent of an essential metabolite required for an enzyme activity. Based on these criteria, the following 17 elements are considered essential for the growth of higher plants: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, zinc, molybdenum, boron, chlorine and nickel. Plant nutritionists and soil scientists would rather have a less restrictive definition for establishing the deficiency symptoms, and so four more elements (sodium, silicon, cobalt, and vanadium) are added to the list of the 17 just listed.

It is now established that sodium is essential to plants with a C<sub>4</sub> photosynthetic pathway. Silicon addition has shown to improve the growth of sugar cane. Cobalt is considered essential for microbial fixation of atmospheric nitrogen. All these are beneficial elements for most crops.

### Aromatic plants

Aromatic plants are those that yield aromatic and fragrant compounds. Mint, lemon grass, jasmine, rose, lavender, etc. are examples of aromatic plants.

### Artesian well

A perpendicular bore sunk into an oblique strata to tap a water-bearing rock or an aquifer lying beneath a relatively impermeable stratum is an artesian well. If the water table at the margins of the aquifer is higher than the outlet of the well, water flows out of the bore under pressure. It may be necessary to cap the well in order to regulate the supply of water for irrigation. Where the well head is above the water level in the aquifer, a condition referred to as a sub-artesian well exists, as distinct from a naturally flowing artesian well. Water has to be pumped to the surface for use.

### Artificial fertilizers

Unlike natural fertilizers, artificial fertilizers (also known as inorganic fertilizers, mineral fertilizers or chemical fertilizers) are mined or made by chemical processes. An artificial fertilizer is sometimes also called bag muck because it is stored in a bag.

### Artificial manure

Artificial manure or synthetic manure is a compost produced primarily from plant residues. (See also Compost.)

## Ash

Ash is a non-volatile solid mineral residue resulting from the burning of organic matter (Fig. A.39).

Ash in analytical chemistry means the inorganic residue of a complete combustion of a material. It consists of mineral matter like  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ , etc. It is an end product of a large-scale combustion of coal (as in power plants) and is said to be the most plentiful mineral.

Ash can be fly ash, bottom ash and boiler ash. There are many uses of fly ash, such as in cement products, as road filling and as an absorbent of oil spills.

The ash content of organic soils is an important component of the soil matrix. Usually, as ash content increases, the available nutrient content of the soil also increases.

The increase of ash content in pit bag soil may be due to several factors, such as mineralization of organic matter, use of mineral fertilizers, introduction of inorganic elements by ground waters, influx of mineral elements during floods and their deposition from the atmospheric dust.

To evaluate plant nutrient content, the plant material is incinerated at about  $600^\circ\text{C}$  and its ash content is analyzed. In this process, inorganic elements other than C, H, O and N can be estimated.

**Ashing** is the burning of material, such as plants. It results in the breakdown of complex compounds into simpler ones and is an important step in analytical work.

Ashing can be effected either by heating the sample (often with sodium carbonate), in which case, it is called **dry ashing**, or by heating with a single or mixed concentrated acid (like perchloric acid, nitric acid or sulphuric acid) in a wet digestion of mineral compounds,

which is called **wet ashing**. **Aqua regia** (which is concentrated nitric acid and concentrated hydrochloric acid in the ratio of 1:3) is commonly used in wet analysis.

**Ashing:** See Ash

## ASN

ASN is short for **ammonium sulphate nitrate**.

## *Aspergillus niger*

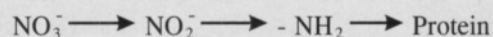
*Aspergillus niger* is a fungus of common occurrence. It is commonly used as a phosphate solubilizing micro-organism and a compost degrading agent.

*Aspergillus niger* is widely used in industry for the production of organic acids (citric, oxalic, gluconic) and enzymes (amylolytic and pectolytic). The fungus is also used in biological soil tests. It is used to assess the available nutrient status of a soil by cultivating it in the given soil under controlled conditions.

## Assimilation

Assimilation is a familiar phrase in all metabolic processes. It leads to the absorption and utilization of food by living organisms for growth, reproduction and repair. This includes absorption and incorporation of nutrients or other inputs (such as carbon dioxide) into photosynthates by plants.

The conversion or transformation of the absorbed nitrate into amino acids and proteins is an example of assimilation, which is similar to photosynthesis:



The ratio of the amount of photosynthesis occurring in a unit mass of the leaf per hour to the weight of the

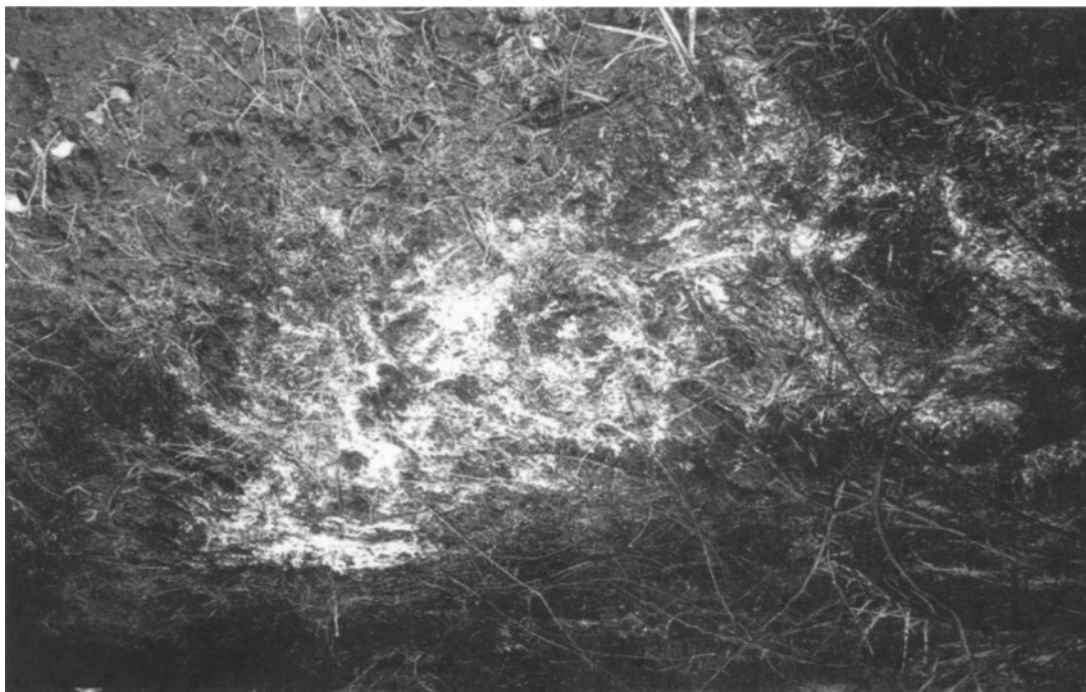
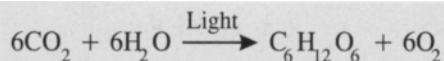


Fig.A.39: Stubbles and crop residues in the field are burnt for field sanitation, the resultant ash supplying mineral elements to the soil.

chlorophyll in the tissue is known as the **assimilation number**. This ratio, in practice, is the weight of carbon dioxide (in mg) absorbed in an hour to the weight of chlorophyll (in mg) in the tissue. The ratio of carbon dioxide absorbed to the oxygen output is the **assimilatory quotient**, which is generally near unity and is represented by:



The energy driving power of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH<sub>2</sub>), which is necessary for the reduction of carbon dioxide to carbohydrate by plants, is called the **assimilatory or reducing power**.

**Assimilation number:** See Assimilation

**Assimilatory power:** See Assimilation

**Assimilatory quotient:** See Assimilation

#### Associated form of ammonium hydroxide

Associated form of ammonium hydroxide is another name for non-ionized molecular ammonium hydroxide. (See Aqua ammonia.)

#### Associated gas

Associated gas is the natural gas which occurs with crude oil and which is released in the separation plant when pressure is released. The composition of natural gas varies with the pressure at which the separator is opened.

#### ASTM

ASTM is short for American Society for Testing and Materials. (See also Sieving.)

#### Atmometer for estimating potential evapotranspiration

Atmometers measure water evaporated from surfaces, such as porous filter papers, porous porcelain spheres or plates. Atmometers are very sensitive to wind speed.

The four classes of atmometers are (a) large evaporation tanks sunk in the ground or floating on protected waters, (b) small, open evaporation pans, (c) porous porcelain bodies, mainly used by plant physiologists in studying evapotranspiration from plants and (d) wet paper surfaces.

#### Atomic absorption spectrometer

Atomic absorption spectrometry (AAS) involves converting a sample at least partially into an atomic vapor and measuring the absorbance of this atomic vapor at a specific wavelength ( $\lambda$ ), to characterize a specific element. The measured absorbance is proportional to the concentration and is compared under the same experimental conditions to that of a reference sample of

known composition.

AAS is used extensively in the analysis of trace elements or micronutrients in fertilized soils as well as elemental contaminants in polluted waters (Fig.A.40).

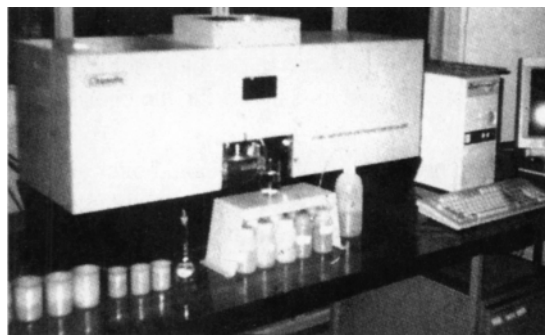


Fig.A.40: Atomic absorption spectrometer.

The advantages of AAS are that it has high sensitivity for as many as 60 elements measurable in the ppm range, and that the measurement is simple, rapid, relatively low-cost and highly specific (with very few interferences).

AAS has four basic components which are (a) a light source, emitting the spectrum of the desired analyte elements, (b) a sample atomization cell, such as a flame or graphite tube furnace, (c) a monochromator to isolate the desired source emission line and (d) a detector/readout system, to allow measurement of change in the source line intensity by sample atom absorption. Many commercial instruments based on either a single or double beam design are available.

#### ATP

ATP is short for **adenosine triphosphate**.

**ATPase:** See ATP hydrolase

#### ATP hydrolase

ATP hydrolase (also called **ATPase**) is an enzyme located in the plasma membrane. It initiates nutrient uptake and hydrolyzes ATP. The hydrolysis results in the splitting of water (H<sub>2</sub>O) into H<sup>+</sup> and OH<sup>-</sup> ions, from which H<sup>+</sup> is extruded into the outer medium, creating a potential difference between two sides of the membrane; the proton motive force thus obtained drives the ion uptake. The plasmalemma-bound ATPase also drives the uptake of anions (NO<sub>3</sub><sup>-</sup> and H<sub>2</sub>PO<sub>4</sub><sup>-</sup>).

The hydrolysis of ATP results in the cleavage of either one phosphate or two phosphate groups with the formation of ADP or AMP. The ATPase activity is associated with many energy-consuming processes. For example, in muscular contraction it is associated with myosine when activated by actin. (See also Nutrient uptake.)

#### Atrazine

Atrazine is the generic name for 2-chloro-4-ethylamino-6-isopropylamino-s-triazine. Atrazine is an example of photosynthesis inhibitors and herbicides.



Atrazine was the first s-triazine used in maize. The use of this herbicide and others in the same group has expanded to selective application in perennial crops and orchids as well as for non-crop and industrial sites.

## ATS

ATS is short for **ammonium thiosulphate**.

## Attapulgite clay

Attapulgite clay is clay from Attapulgus, Georgia, USA. It is hydrous, needle-like magnesium aluminum silicate  $[(MgAl)_5Si_8O_{22}(OH)_4 \cdot 4H_2O]$  and is the chief ingredient in Fuller's earth. It is used as a suspending agent in fertilizers, lime, gypsum, etc. and has absorptive and swelling properties.

Attapulgite clay is also used in drilling fluids, decolorizing oils and as a filtering medium.

## Attractants

With growing need for an environmentally acceptable pest control method, the use of specific insect attractants has become an important part of pest control technology. Chemical attractants can be used in conjunction with simple, inexpensive sticky traps for monitoring insect pest populations in relation to the economic threshold for control and/or trapping of pests, for luring them to toxic bait, or for creating confusion during mating.

Two general types of attractants have been studied widely. These are (a) sex pheromones, used in intraspecies chemical communication leading to mating and (b) plant kairomones, used in interspecies chemical communication for host plant selection.

**Sex pheromone** attractants are generally volatile esters, alcohols and aldehydes that facilitate sexual communication and mating over distances up to several hundred meters and can be perceived in nanogram to microgram quantities.

**Kairomone** attractants are volatile chemicals released by plants, which serve as major cues host plant selection by phytophagous insects. Increasing numbers of kairomones have been identified and found to be useful insect attractants. The most successful mixtures are eugenol with geraniol or phenyl ethyl propionate.

## Auger

An auger or **soil auger** is a tool with a pointed tip used for boring holes in the soil for collecting soil samples for analysis. Augers are of two types: worm-type and hollow cylinder type, with a cutting edge or a screw at one end.

## Auger fertilizer distributor

An auger-type fertilizer distributor is an implement that can evenly distribute the exact amount of a fertilizer in all directions, rendering width and flexibility to band applications.

The distributor has spreaders with a mechanical

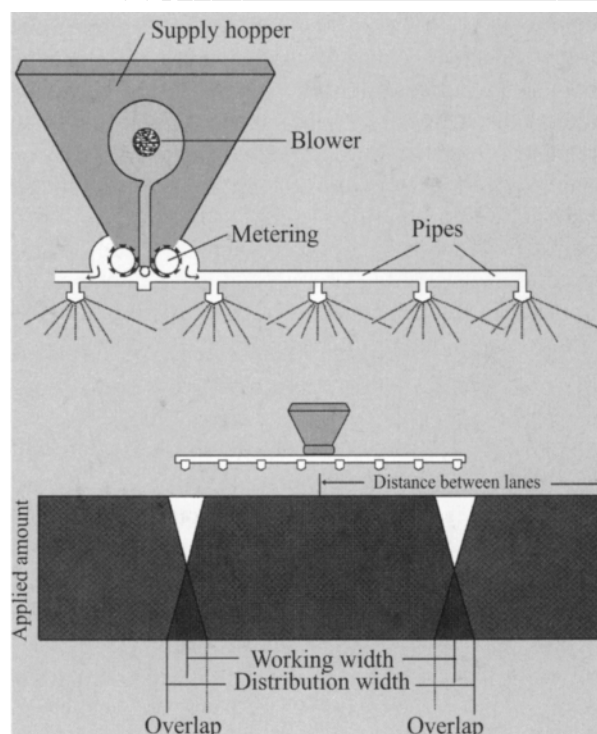


Fig.A.41: Auger fertilizer distributor.

traverse distribution, generally equipped with a screw or auger, called **auger-type spreaders**. The fertilizer flowing from the hopper is conveyed to the auger and is transported to the spreader tubes with adjustable discharge spouts with a working width of 6 to 8 m depending on the boom length (Fig. A.41).

For the application of powdered fertilizers, **auger type spreaders** with identical boom lengths and working widths are preferred. For uniform fertilizer distribution, the exact driving of the distributor in parallel runs is essential. To improve the metering and distribution of mineral fertilizers, electronic control units ensure an automatic discharge of desired amounts of the fertilizer as indicated on the display panel.

## Auger type spreader

Auger type spreader is a device used for applying powdered fertilizers. It has electronic control units which ensure an automatic discharge of desired amounts of the fertilizer as indicated on the display panel. (See also Auger fertilizer distributor.)

## Autecology

Autecology is the study of environmental relations of individuals or species. (See also Ecology.)

## Auto allelopathy

Auto allelopathy is the inhibition of a species by self-produced toxins. (See also Allelopathy.)

## Autochthonous limestone

Limestone has two origins. One is autochthonous limestone and the other is **allochthonous limestone**. Autochthonous limestone is formed in-place by the

biogenic precipitation from sea water. The primary agents of autochthonous limestone are lime-secreting organisms and foraminiferans, which are marine protozoans with a secreted shell. Fossils of such organisms, having a long geological history, have been found embedded in such limestone and other carbonate material. Thus, limestone itself has been an object of interest to geologists and other scientists. Study of the structure of caves has also revealed that autochthonous limestone in fluvial sediments is in the form of angular softened limestone embedded in clay.

### Autoclave

An autoclave is a cylindrical vessel with a double wall chamber, which withstands pressure (like  $2.1 \text{ kg/cm}^2$ ) operations (Fig.A.42). It sterilizes solids and liquids used in the laboratory to overcome contamination. This equipment is essential in microbiology, pathology and tissue culture studies. Sterilization is achieved mainly by an air-free saturated steam inside the autoclave at a temperature of above  $100^\circ\text{C}$ . The boiling water produces steam which creates pressure inside the autoclave chamber. The temperature rises as the pressure increases to  $1.05 \text{ kg/cm}^2$ . When the temperature goes up to  $121^\circ\text{C}$  and is retained at this level for a specified time (normally 15 minutes), the vegetative cells and spores are destroyed. If the evacuation of air is incomplete, pressure builds up without a proportional rise in temperature. After the operation, it is necessary to wait for the pressure to decrease to ambient to avoid harm by the boiling water inside the autoclave.

### Autogamy

Autogamy is one of the two types of fertilization, also known as **self-fertilization**. Here, the pollens are carried from an anther to the stigma of the same flower or to another flower of the same plant. Autogamy is found, for instance, in wheat, oats and peas.

### Autotrophic bacteria

Autotrophic bacteria are **bacteria** that produce organic

constituents from inorganic compounds on their own, utilizing energy from sunlight for oxidation processes. Depending on the source of nutrition and energy, soil bacteria are classified as autotrophic, which obtain energy from (a) sunlight (**photoautotrophs**), or (b) the oxidation of minerals such as ammonium, sulphur and iron, and most of the carbon from carbon dioxide (**chemoautotrophs**). Bacteria which oxidize ammonium to nitrite (*Nitrosomonas* spp.) and nitrite to nitrates (*Nitrobacter* spp.) are autotrophic.

### Auxins

Auxins are a group of growth-promoting substances, responsible for such plant related processes as promotion of longitudinal growth by cell elongation, stimulation of cell division in **cambium** and roots, maintenance of apical dominance and initiation of root formation in cuttings, as well as in the control of enzyme activity.

Naturally occurring auxins, such as **indoleacetic acid (IAA)** and **4-indole-3-butyric acid (IBA)**, are synthesized in the plant shoot tips. Auxins, important as growth regulators, include (a) indole-3 acetic acid, (b) 4-indole-3 butyric acid, (c) 2-(1-Naphthyl) acetamide and (d) 2-(1-Naphthyl)oxy) acetic acid.

**Synthetic auxins**, known by various trade names such as 2,4-D and 2,4,5-T are used as weed killers. Some synthetic auxins are used for inhibiting the sprouting of potato tubers, thereby increasing their storage life. Auxins are also used in the prevention of fruit drop in orchards, synchronous flowering in pineapple and parthenocarpic fruit production.

Auxins have not gained much practical importance as growth stimulators owing to their narrow therapeutic range. Moreover, a small overdose can lead to a herbicidal effect. Therefore, auxin type substances are much more important as herbicides than as growth regulators.

**Antiauxins** are substances that compete with auxins for specific receptors. They inhibit the transport of auxins in the plant and thus strongly affect plant growth



Fig.A.42: Types of autoclave. 1. Vertical type, 2. horizontal type.

and morphology. **N-m-tolylphthalamic acid, (N-m-t)** improves the yield of tomatoes, cherries, eggplants and lima beans by increasing fructification.

There are four bioassays commonly employed for auxins. These are (a) avena curvature test, (b) avena straight growth test, (c) pea split stem curvature test, and (e) cress root inhibition test.

**Auxotrophic micro-organisms:** See Auxotrophs

**Auxotrophs**

Auxotrophs or **auxotrophic micro-organisms** are micro-organisms which cannot synthesize essential growth factors and need to acquire these from external sources. The external sources include organic compounds, vitamins, etc. *Bacillus anthracis* is a thiamine auxotroph, as it does not synthesize the thiamine required for its growth.

**Available biogenic element**

Available biogenic element is another term for **available element**.

**Available element**

Available element, also called **available biogenic**

**element**, is one that can be absorbed directly by the plant. Such a substance has to be in a mineral and ionized form. Its availability depends on its solubility in soil water and in solutions in contact with the roots.

The availability (not to be confused with 'exchangeable') of a biogenic element is difficult to determine. Because the availability depends on the combination of three complex factors, namely (a) the plant itself, (b) the force of retention of the element by soil colloids and (c) the content of the element in the soil.

Soil pH can strongly influence the availability of essential and non-essential elements for plant growth, as shown in Fig. A.43.

**Available form**

A form in which an element can be absorbed by the plant is called the available form.

That water in the soil, which the plant roots can absorb to sustain life, is called **plant available water**. It is the moisture held with water potential between minus 13 to minus 15 bars.

In fertilizer terminology, for example, terms like **water-soluble**, citrate-soluble, citrate-insoluble, available form and **total phosphorus** ( $P_2O_5$ ) are used to delineate different forms of phosphorus available in a

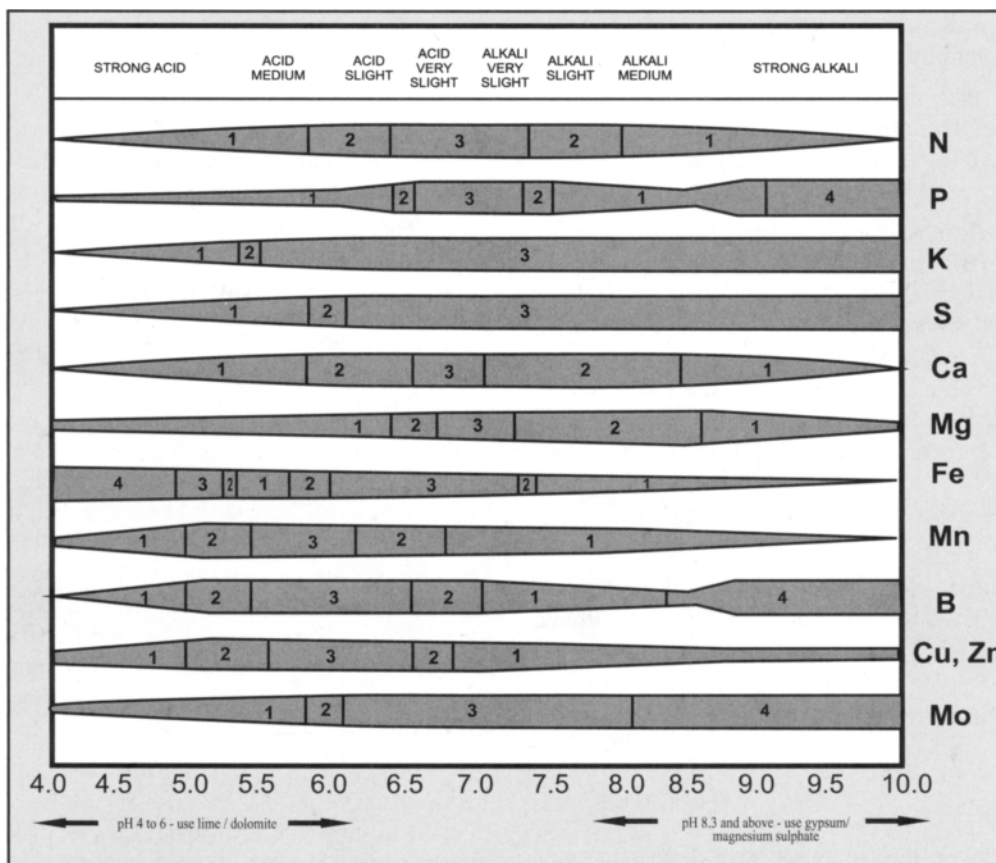


Fig. A.43: A bar diagram showing the effect of soil pH on the availability of plant nutrient elements. Nutrient availability increases or decreases as per the thickness of the bar. The thicker the bar, the more the availability, and vice versa. Similarly, the number code - 1 indicates very little availability, 2, marginal availability, and 3, sufficient availability. Even though the bar is thick, the number code 4 signifies very little availability because of the absence of complementary elements and soil interactions. Courtesy: Institute of Micronutrient Technology, Pune, India.

**phosphate fertilizer.** The sum of the water-soluble phosphorus and the citrate-soluble phosphorus represents the amount of available phosphorus (as  $P_2O_5$ ).

Generally, plant roots and foliage absorb plant nutrients as water solutions of a variety of chemical compounds with varying degrees of water solubility. Thus, water solubility provides a simple conclusive measure of the 'available' nutrients to plants.

### Available nutrients

Available nutrients are soil substances that can be readily absorbed and assimilated by growing plants. Available nitrogen is defined as water-soluble nitrogen plus a part of it that can be made soluble or converted into free ammonia. **Available phosphorus** is that part of phosphorus which is soluble in water or in a weak dilute acid, such as 2% citric acid. Available potash is defined as that portion of potash which is soluble in water or in a solution of ammonium oxalate.

### Available phosphorus form

A sum of the fraction of water-soluble and citrate-soluble phosphorus available to plants is called available phosphorus.

The content of fertilizers is expressed as 'water-soluble', 'citrate-soluble', 'citrate-insoluble', total available phosphorus (as  $P_2O_5$ ), etc., because the phosphorus solubility of fertilizers varies.

Available phosphorus in fertilizers represents an estimate of the fraction of the sum of water-soluble and citrate-soluble phosphorus available to plants.

The technique of citrate extraction is useful in determining all phosphates, such as calcium hydrogen phosphate ( $CaHPO_4$ ), which are insoluble in water but soluble in citrate solutions. The most common methods in Europe use ammonium citrate solutions (1N) where extraction is performed in a strong alkaline medium or neutral citrate solution. Very often, the extraction is carried out for 30 minutes at room temperature, and is followed by a treatment at 40°C. For neutral citrate extraction, 65°C is the prescribed temperature. The phosphorus content in the filtrate is termed as citrate-soluble.

Most countries in the world use neutral ammonium citrate solution for extracting the citrate soluble phosphorus.

**Available potassium in soil:** See Exchangeable potassium

### Available water

Available water is the soil water that plant roots can readily absorb. It is the water held in the soil against a pressure of about minus 15 bars. Water held in the soil between field capacity and wilting point is the available water.

To evaluate the total quantity of water accessible to plants (called the **useful available water, UAW**), it is

necessary to include the rooting depth ( $P$ ) as well as the bulk density ( $D$ ) of the soil. Thus,

$$UAW = (PD)(c-w)$$

where  $c$  is the field capacity water percentage and  $w$  is the wilting point water percentage.

### Available water capacity

Available water capacity is the quantity of water that a soil is capable of holding between the field capacity and the permanent wilting point. It is expressed on a volume basis in units of mm of water per 100 mm depth of soil.

The concept of field capacity, while useful for setting up an upper limit to the amount of available water in the soil, is not precise for two reasons: (i) The soil may remain saturated above the field capacity owing to frequent rains for several days. (ii) Soil with a high proportion of micropores continues to drain slowly for several days after the rains. (See also Field capacity.)

### A value

The A value for a plant is the quantity of a nutrient available to it in the soil medium. It is determined in terms of a standard fertilizer used, and is expressed as:

$$A = \frac{B(1-y)}{y}$$

where  $B$  is the quantity of nutrient in the applied fertilizer and  $y$  is the proportion of nutrient in the plant derived from the fertilizer.

The A value is determined by a tracer technique; **Fried and Dean** method for estimating nitrogen in the soil uses a labelled fertilizer. This method involves adding known quantities of  $^{15}N$  labelled nitrogen to the soil, growing plants and determining the relative amounts of soil and labelled nitrogen taken up by the plants. A key assumption is that plants take up the soil nitrogen and the labelled nitrogen in proportion to their effective concentration in the soil.

The isotope dilution technique is used to estimate the availability of soil nitrogen and other plant nutrients in absolute units. This method assumes that (a) the labelled fertilizer is mixed uniformly with the exact volume of the soil foraged by the plant roots, (b) the added nitrogen is not lost selectively from the soil after application, and (c) transformations, such as immobilization and mineralization, occur only insignificantly during the period of study. However, some of these assumptions need further scrutiny.

The A value is used for the assessment of the available soil nutrients like N, P or S. The nitrogen isotope  $^{15}N$  occurs in atmospheric nitrogen at a constant abundance of 0.3663 atom percent. The proportions of leguminous plant nitrogen derived from atmospheric nitrogen and soil nitrogen can be determined if the isotopic abundance of atmospheric nitrogen and the soil nitrogen are significantly different. This can be achieved by incorporating small amounts of nitrogen fertilizer enriched in  $^{15}N$  into the soil.

The symbiotically fixed nitrogen by a legume in the field is estimated by a simultaneous determination of the A value of a non-legume along with the legume crop. The A value of a non-legume crop represents the soil nitrogen as the principal source, while the A value of the nodulating legume crop represents the symbiotically fixed nitrogen, in addition to the soil available nitrogen. The difference in the A values provides an estimate of the symbiotically fixed nitrogen by a legume.

### Average soil

Average soil is represented by the NF (numerical estimation of fertility) value of 50. (See also Fertility, numerical estimation of.)

**Avogadro's constant:** See Avogadro's number

### Avogadro's number

Avogadro's number ( $N_A$ ) =  $6.0221367 \times 10^{23}$  represents the number of carbon-12 atoms in 12.00 g of carbon-12. Generally, it is the number of molecules contained in one mole or gram molecular weight of a substance.

Presently, Avogadro's number is known as **Avogadro's constant**. There are several methods for determining Avogadro's number, some of which use (a) Brownian movement, (b) radioactivity measurement, (c) Faraday's laws of electrolysis and (d) x-ray diffraction.

### AVO meter

AVO meter is another name for a **multimeter**. It is used to measure the resistance or conductivity of soil.

### AZF-Grand Paroisse dual pipe-reactor process for ammonium phosphate nitrate production

There are several processes to produce fertilizers containing ammonium phosphate and ammonium nitrate. Most of these are also used to produce the NPK grades.

The AZF-Grand Paroisse dual pipe-reactor process is one of the processes in which ammonium nitrate solution is sprayed directly on fertilizer granules in the granulator to produce ammonium phosphate nitrate (APN) fertilizer. APN solutions are also made by neutralizing phosphoric acid with ammonia and ammonium nitrate.

**AZF-Grand Paroisse prilling process for ammonium nitrate production:** See Ammonium nitrate, production processes for

### Azofication

Azofication is **nitrogen fixation** without symbiosis. The soil bacteria of the *Azotobacter* group use organic matter as the energy source and fix nitrogen for their own use, which returns ultimately to the soil after the bacteria die.

### Azolla

The word *Azolla* originates from two Greek words, *Azo* (to dry) and *Olyo* (to kill), indicating that the fern is killed by drought.

*Azolla* is a greenish colored fern floating on fresh water and is used as a **biofertilizer**. The reddish color of the fern is due to the accumulation of anthocyanin pigment.

*Azolla* belongs to the family Azollaceae. It flourishes in tropical and temperate fresh water ecosystems. *Azolla* is closely related to the family Hymenophyllaceae, and specifically to the order Salyniales.

There are seven species of *Azolla*: *Azolla caroliniana*, *A. nilotica*, *A. filiculoides*, *A. mexicana*, *A. microphylla*, *A. pinnata* and *A. rubra*.

*Azolla pinnata* is the most common species, found in tropical climates. It grows in ditches and stagnant water, and multiplies vegetatively (Fig.A.44). The vegetative multiplication is caused by binary fission. In suitable conditions, *Azolla* doubles in 1 to 3 days, though in fields it takes longer. It fixes atmospheric nitrogen in symbiotic association with *Anabaena azollae*, a blue green alga, which lives in the dorsal cavity of the leaf.

Leaves of *Azolla* are triangular or polygonal in shape and have a dorsal and a ventral lobe. The symbiotic algae, *Anabaena azollae*, live in the cavities of the dorsal lobe. The algae are barrel shaped and have no sheath. The *Azolla* fern and the symbiotic *Anabaena azollae* (algae) both photosynthetically make an important **biofertilizer**. *Azolla* gets carbon photosynthetically and symbiotic *Anabaena azollae* fix atmospheric nitrogen.



Fig.A.44: *Azolla* grown in pots. It is also grown in ponds for large scale production.

*Azolla* is recommended for rice fields with stagnant water. It can increase the rice yield by 15 to 20%. The importance of this biofertilizer is its value as an organic input in rice cultivation, which was first demonstrated in Vietnam in 1957.

In China, the nitrogen requirement of rice is met by *Azolla* to the extent of 50%. This is generally applied along with phosphorus at the rate of 150 to 225 kg of **superphosphate** per hectare (24 to 36 kg  $P_2O_5$  or 11 to 16 kg phosphorus/hectare). Indian studies have indicated that the addition of 5 t/ha of *Azolla* can provide an equivalent to 30 kg nitrogen/hectare to the paddy crop.

In countries like India, there are two recommended methods for applying *Azolla*. Application as green manure prior to rice planting is the first method; the second method involves a dual cropping with rice, where the *Azolla* grows simultaneously with the main crop.

Before transplanting rice seedlings, the field is prepared for *Azolla* inoculation by dividing it into subplots of about 300 to 400 sq.m. in each area. These plots are flooded with water and inoculated with fresh *Azolla*. After 2 to 3 weeks, the water is drained out and *Azolla* is incorporated into the soil. In a week's time the rice seedlings are transplanted to the plots. Ideally, an optimum level of temperature and moisture has to be maintained with adequate supply of nutrients, especially of phosphorus.

*Azolla* cannot be advantageously used in areas that have no water, or, where pests and adverse temperatures prevail. It perishes quickly if removed from water and is thus not amenable to long distance transportation.

*Azolla* finds use as green manure, as fodder for livestock, as a weed suppressant and as composting material.

### Azolla-Anabaena symbiosis

The *Azolla-Anabaena* symbiosis is one in which the fern *Azolla* provides a habitat and carbon source to the blue-green alga, the *Anabaena azollae*. In turn, the *Anabaena* lives and grows in the cavity of the *Azolla* fern, fixing atmospheric nitrogen (Fig.A.45). While the fern can grow without algae, it is now established that *Anabaena azollae* can also be isolated and grown in free living state.

The algae provide nutrients, whereas the fern provides a protective cavity in each of its leaves for algal

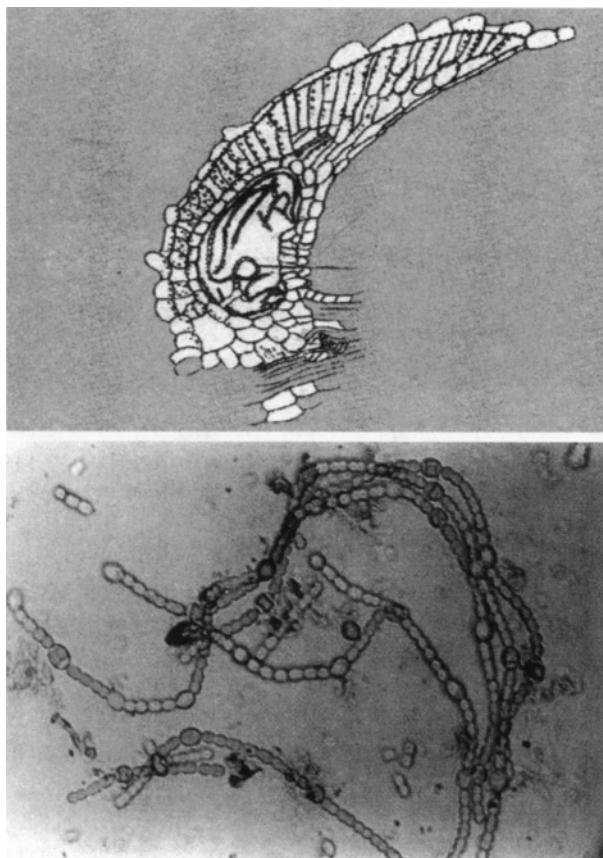


Fig.A.45: *Azolla-Anabaena* symbiosis. (Top) *Anabaena azollae* in the cavity of *Azolla* leaf. (Bottom) Microscopic view of *Anabaena azollae*. (Courtesy: Dr.P.L. Patil, Pune, India).

colonies. *Anabaena azollae* creates colonies that fix atmospheric nitrogen and produce possibly other substances, promoting growth inside the *Azolla* leaf cavities.

Ammonia produced by *Anabaena* is used or stored by the algae, or it is supplied to the *Azolla* partner. This puts *Azolla* in a more advantageous position than other aquatic plants in low nitrogen supply conditions.

### Azolla pinnata

*Azolla pinnata* is one of the seven species of *Azolla*, a fresh-water fern (Fig.A.46). It fixes atmospheric nitrogen in symbiotic association with *Anabaena azollae*, a blue-green alga, which lives in the dorsal cavity of the fern leaf.

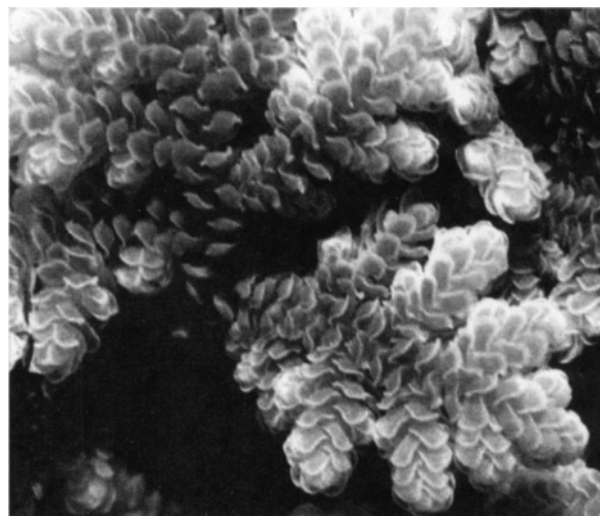


Fig.A.46: A close-up of *Azolla pinnata*.

### Azospirillum

*Azospirillum* is an associative micro-aerophilic nitrogen fixing bacterium, commonly found in association with the roots of cereals, grasses and monocotyledonous plants. It is suitable for use in tropical conditions because of its high nitrogen fixing capacity, low energy requirement and tolerance to high temperatures (30 to 40°C).

The known species of *Azospirillum* are: *A. lipoferum*, *A. brasilense*, *A. amazonense*, *A. halopraeferns*, *A. irakense* and *A. melinis*. Different culture media are developed for *Azospirillum*. Its cell is 1 mm in diameter. It looks like a curved rod and may vary in size. The bacteria are chemoheterotrophic and associative.

The bacteria are aerobic organisms which derive food and energy from carbon sources like mono, di, and polysaccharides (L-arabinose, D-glucose, D-fructose, sucrose and pectin). The nitrogen source is through the fixation of nitrogen, amino acids, ammonium, nitrate ions, etc. A nitrogen-free medium is desirable for the growth of *Azospirillum*. In an ammonia-containing medium, *Azospirillum* doubles in an hour, but in a malate-containing medium, it doubles in 5.5 to 7 hours. *Azospirillum* sp. increases mineral and water uptake of the plants it associates with and also helps root development and vegetative cover.



*Azospirillum*, a biofertilizer, is recommended for rice, millets, maize, wheat, sugar cane, sorghum, sunflower, mustard, vegetables, etc. (Fig.A.47). Its inoculation has shown positive interaction; nitrogen thus supplied in several field crops has shown an average response equivalent to 1.5 to 20 kg/ha of applied nitrogen.

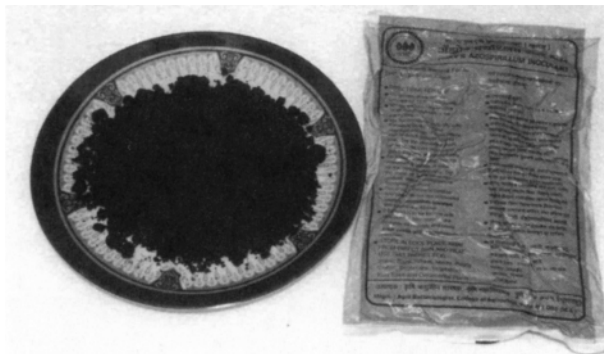


Fig.A.47: *Azospirillum* inoculant. These nitrogen fixing bacteria are commercially available for all non-legume crops.

In a study carried out at Delhi and Dehradun in India, inoculation with *Azospirillum* showed a significant increase of irrigated barley yield with very little or no fertilizer nitrogen application. A dual inoculation of *Azospirillum* and *Azotobacter* could save approximately one-third the quantity of nitrogen fertilizer used.

*Azospirillum* also produces growth producing hormone-like substances, and is now classified as a PGPR (plant growth promoting rhizobacteria). It is beneficial as an inoculant even in the presence of fertilizer nitrogen.

In order to utilize associative diazotroph under adverse conditions, mutants have been obtained that are tolerant to manganese and aluminum, and that perform better in acidic soils. Several carriers have been tested for the survival of *Azospirillum*. Among these, powdered and sterilized farmyard manure (FYM) was seen to support the survival of *Azospirillum* organism for up to 31 weeks. Other combinations tried were FYM + soil and FYM + charcoal. *Azospirillum* biofertilizer has been widely adopted as an inoculant for rice in Tamilnadu, India, where it is supplied in lignite carriers and applied both by dipping the seedlings in inoculant slurry as well as by soil application.

## Azote

Azote is a French word, meaning nitrogen. A bacterium is named *Azotobacter* for its atmospheric nitrogen fixing characteristics.

## Azotobacter

*Azotobacter* is a bacterium capable of fixing atmospheric nitrogen. It is one of the dominant non-symbiotic nitrogen-fixing bacteria, encountered in neutral to alkaline soil conditions. These species are free-living obligate aerobes, heterotrophic and Gram negative to Gram variable. They exist as blunt rods and come in varied sizes (2.0 to 7.0 × 1.0 to 2.5 μm). They produce soluble, insoluble or fluorescent colors.

The oval shaped *Azotobacter* is present in large numbers in the rhizosphere. It does not attach itself to roots. Because *Azotobacter* synthesizes its nutritional requirements from organic matter, it is called heterotrophic. As it derives its energy from oxidation of organic substances, it is said to be chemoheterotrophic. *Azotobacter* uses mono, di, and polysaccharides, as well as several other organic compounds as carbon sources. It forms cysts to overcome adverse conditions which are characterized by the presence of poly β-hydroxy butyric acid. As the colony (for example, *Azotobacter chroococcum*) gets older, it accumulates polysaccharide or gum, together with a black melanin pigment, which is another characteristic feature of the *Azotobacter* species. These organisms grow when the pH is near neutral, but pH below 6 hampers the process of nitrogen fixation.

Another important characteristic of *Azotobacter* is that it excretes ammonia in the rhizosphere in the presence of root exudates, which helps nutrient uptake by the plant. Plant root exudates contain certain amino acids, sugars, organic acids and vitamins, which serve as energy sources for *Azotobacter*.

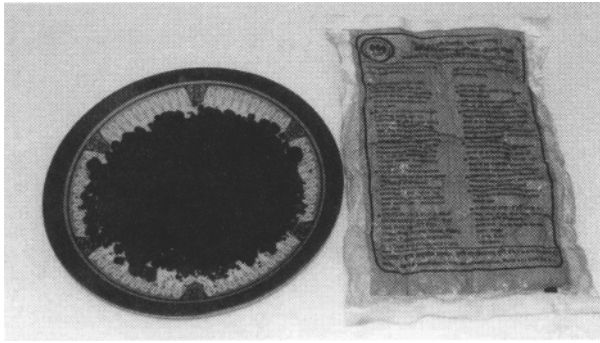
Species like *Azotobacter chroococcum* have the ability to synthesize auxins, vitamins, growth promoting substances and antifungal antibiotics. Some important growth promoting substances are indoleacetic acid, gibberellins and B vitamins.

Free-living, nitrogen-fixing bacteria are classified into aerobic, anaerobic and facultative anaerobic types, depending on the growth and survival pattern of the organisms, either in the presence or absence of oxygen. The aerobic bacterium fixes nitrogen (which is an anaerobic process) by protecting the enzyme nitrogenase from oxygen inactivation. This is primarily by virtue of its very high respiratory rate, which constantly removes oxygen from the active sites of fixation. The nitrogenase enzyme is also bound to membrane and the active sites of the enzyme are physically protected from oxygen inactivation.

*Azotobacter* fixes molecular nitrogen at the rate of 10 mg nitrogen/g of carbon source from the synthetic medium. *Azotobacter* fixes nitrogen even up to 1050 microgram nitrogen/ml of the culture medium, which amounts to 14 to 28 mg nitrogen/g of carbon source. The efficiency of nitrogen fixation, however, changes considerably with the source of carbon present, the strain of bacteria in the soil, the water content and the nature of rhizosphere of the plant.

The following factors influence the bacterium in the soil: (i) A lack of organic matter can inhibit its growth. (ii) The presence of fungi (like *Cephalosporium*) inhibits the growth of *Azotobacter*. (iii) Cellulolytic microorganisms degrade plant residues and encourage proliferation of *Azotobacter*. (iv) Small amounts of humus promote the growth and nitrogen fixation capacity of *Azotobacter*.

*Azotobacter* biofertilizer (Fig.A.48) is recommended for various monocots and cereals, like rice, wheat, millets, cotton, sunflower, vegetables and flowers.



*Fig.A.48: Azotobacter inoculant is commercially available in packets for monocot and cereal crops.*

The *Azotobacter* biofertilizer can be applied in three different ways: (a) coating seeds with the slurry of the carrier-based culture and a little water, and then drying the seeds in shade before sowing, (b) dipping the roots of seedlings in the slurry. In the second method, when saplings are ready for transplanting, they are uprooted and their roots are dipped in the slurry for 10 to 30 minutes, after which seedlings are planted immediately, and (c) mixing the inoculant with farmyard manure and pouring it near the root zone of plants or broadcasting near the root zone.