
Factors influencing the content of nitrogen in soil

The ultimate source of nitrogen used by the plants is the inert gas nitrogen, which constitutes about 78 % (by volume) of the earth's atmosphere. Among all the essential nutrients, nitrogen is the extensively studied one and still receiving much attention.

The ploughed layer of majority of cultivated soils contains about 0.02 – 0.04 % nitrogen. Indian soils have very low content because of low organic matter accumulation due to tropical climate. Soils developed under cool humid climate have higher N content than those formed under dry climate. On an average, black soils have more nitrogen content (0.08%) than red soils (0.03%).

Factors influencing the content of N in soils

a) Climate

- i) Temperature: Lower the temperature higher is the N content due to more organic matter addition and slow rate of decomposition.
- ii) Water supply: Soil N content increases with water supply up to field capacity.

b) Effect of cultivation: N content decreases with cultivation due to organic matter loss through decomposition.

c) Soil texture: Finer the texture, higher is the N content.

d) Depth in the profile: Surface soil has more N content than deeper soils.

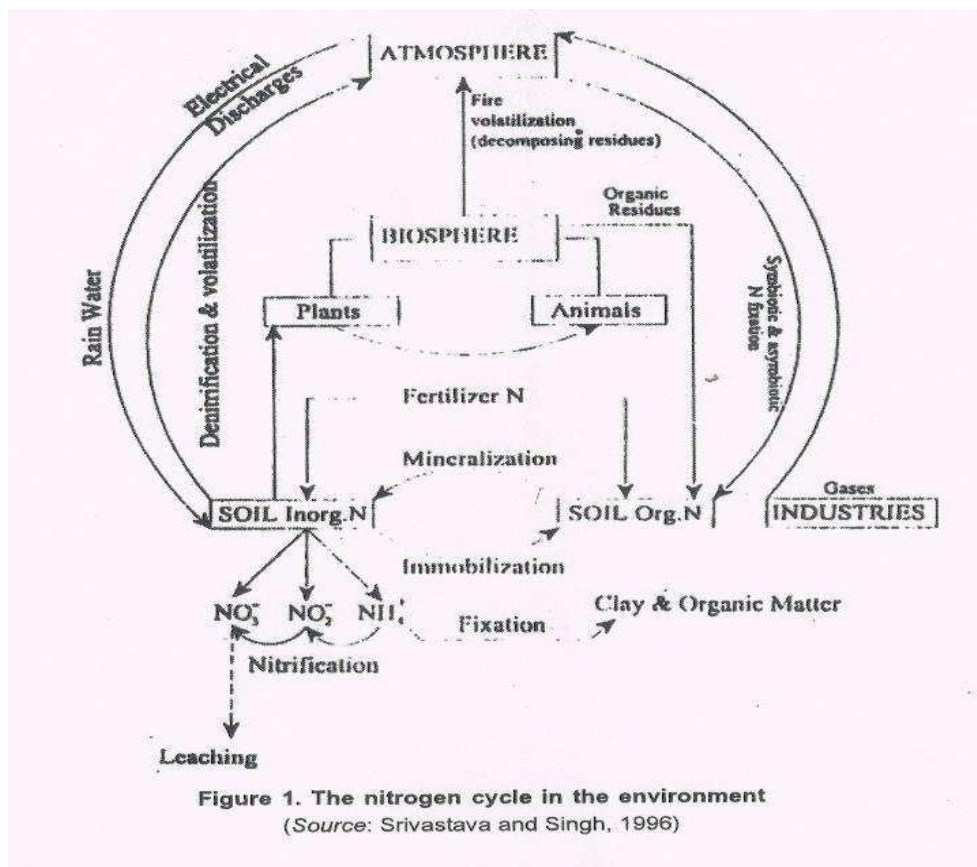
Forms of soil nitrogen:

The total nitrogen content of soils ranges from less than 0.02 % in sub soils to more than 2.5 % in peat soils. The N present in soil can generally be classed as inorganic (around 2 %) and organic (around 98 %).

1. **Inorganic nitrogen compounds:** The inorganic forms of soil nitrogen include ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), nitric oxide (NO) nitrous oxide (N_2O) and elemental nitrogen. NH_4^+ , NO_3^- and NO_2^- are important in soil fertility and represent 2 to 5 % of total

nitrogen.

2. **Organic nitrogen compounds** : occur as consolidated amino acids or proteins, free amino acids, amino sugars and other unidentified compounds like materials that result from the reaction of NH_4^+ with lignin, polymerisation of quinones and nitrogen compounds, the condensation of sugars and amines. Bound amino acids are to the extent of 20-40 %, amino sugars (hexosamines) 5 to 10 %, purine and pyrimidine derivatives 1 % or less.



N transformations in soil: Plants absorb most of the N in the NH_4^+ and NO_3^- forms. Nitrate is the dominant source as its concentration is higher than NH_4^+ and it is free to move to the roots. Potatoes, sugarbeet, pine apple, prefer both the forms; tomatoes, celery, bush beans, prefer NO_3^- , rice and blue berries prefer NH_4^+ .

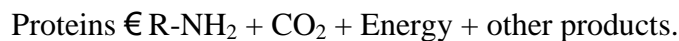
NO_3^- -N uptake is usually high and is favoured by low pH conditions.

NH_4^+ -N is less subjected to losses by leaching and denitrification. NH_4^+ uptake is best at neutral pH values. When the plants are supplied with NH_4^+ -N, it leads to acidity in the soil.

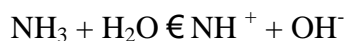
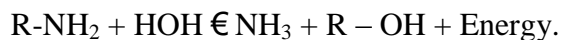
Mineralization of N compounds: N mineralization is simply the conversion of organic nitrogen to mineral form (NH_4^+ , NO_3^- , and NO_2^-). When organic residues having a C: N ratio wider than 30 are added to the soil, immobilisation of nitrogen takes place. If C:N ratio is narrow i.e., less than 20 (for legume residues), mineralisation is the result. It takes place essentially by three steps.

1. Aminisation
2. Ammonification
3. Nitrification.

1. **Aminisation:** Heterotrophic soil microbes, mostly, bacteria like *Pseudomonas* and *Bacillus* are believed to dominate in the break down of proteins in neutral and alkaline soils. Under acidic conditions fungi prevail. In this step hydrolytic decomposition of proteins and release of amines and amino acids takes place.

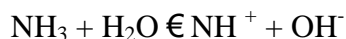
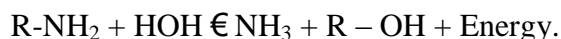


2. **Ammonification:** The amines and amino acids so released are further utilized by still other groups of heterotrophs with the release of ammoniacal compounds. The step is termed as ammonification.



The ammonium thus formed may be nitrified to nitrite and nitrate which are used by plants.

3. **Ammonification:** The amines and amino acids so released are further utilized by still other groups of heterotrophs with the release of ammoniacal compounds. The step is termed as ammonification.



The ammonium thus formed may be nitrified to nitrite and nitrate which are used by

plants.

Fate of released ammonium in the soil

1. It may be converted to nitrites and nitrates by the process of nitrification.
2. It may be absorbed directly by higher plants.
3. It may be utilized by heterotrophic organisms in further decomposing organic carbon residues.
4. It may be fixed in biologically unavailable form in the lattice of certain expanding type clay minerals.
5. It could be released back to the atmosphere through volatilization

Ammonium fixation

In agricultural soils, 5 – 20 % of the total nitrogen is found as fixed ammonium ion, with an average of 10 %. When ammonium containing or ammonium forming fertilizers are added to the soil, most of ammonium gets adsorbed on the cation exchange sites, but a part of it is susceptible to strong adsorption in the interlayer spaces of some 2:1 layer silicate clay minerals with an expanding lattice. The order of fixation is as follows: vermiculite > fine grained mica > smectites.

The ammonium ion has an ionic diameter 2.96 \AA , which is close to the 2.8 \AA diameter of inter lattice spaces in 2:1 type clay minerals. Fixed ammonium is not easily available for plants and microbes. It comes out by a replacement of NH^+ for inter layer cations in the expanded lattices of clay minerals. The fixed ammonium can be replaced by cations that expand the lattice like Ca^{2+} , Mg^{2+} , Na^+ .

The presence of K^+ (ionic diameter of 2.68 \AA) will often restrict NH^+ fixation since this ion can also fill fixation sites. Consequently it has been suggested that K fertilization prior to NH^+ application is a practical way of reducing NH^+ fixation.

Ammonium can also be chemically fixed or bound by the organic matter. The reactions take place most readily in the presence of oxygen and at high soil pH. In organic soils with high fixing capacity, the reaction could result in a serious loss of available nitrogen and would dictate

the use of fertilizers other than those that supply NH_4^+ however, the fixed NH^+ will be slowly released by mineralization.

Factors affecting ammonium fixation

- 1. Type and amount of clay:** NH_4^+ fixation increases with increase in the content particularly 2:1 type of clay minerals like vermiculite, fine grained mica and smectite.
- 2. Moisture content of the soil:** The moisture content and temperature of the soil will affect the fixation of NH_4^+ . Freezing and drying increases the fixation. Alternate cycles of wetting and drying; freezing and thawing are believed to contribute to the stability of recently fixed NH_4^+
- 3. Amount of K^+ :** The presence of K^+ will restrict NH_4^+ fixation since K^+ also fills the fixation sites.
- 4. Depth of the soil:** Fixation of NH_4^+ is generally higher in sub soil than surface soil due to higher clay content and lower rate of nitrification.
- 5. Organic matter content:** Higher the organic matter content more is the NH_4^+ fixation.
- 6. Population of nitrifying bacteria:** Nitrifying bacteria oxidize NH_4^+ to nitrite and nitrates thus reducing the chances for NH_4^+ fixation.

Nitrification – Factors affecting nitrification – Fate of nitrate nitrogen – Leaching losses of nitrate nitrogen – Denitrification – Nitrification inhibitors – Immobilisation

Nitrification: The biological oxidation of NH^+ released by the process of ammonification to nitrate is known as nitrification. This process is carried out by nitrifying bacteria referred to as nitrifiers. It is a two step process in which NH_4^+ is first converted to nitrite (NO_2^-) and then to nitrate (NO_3^-). Conversion to nitrite is brought about largely by a group of obligate autotrophic bacteria known as *Nitrosomonas* as



The conversion from nitrite to nitrate is affected by *Nitrobacter* as follows :



Factors affecting nitrification

- i) **Supply of the ammonium ion:** Because the substrate for the nitrifying bacteria is the ammonium ion, a supply of this ion is the first requirement for nitrification.
- ii) **Population of nitrifying organisms:** Under similar conditions of temperature, moisture and added ammonia, the nitrification is greatly influenced by population of nitrifying bacteria.
- iii) **Soil reaction:** Nitrification takes place between pH of 5.5 to 10.0, with an optimum around 8.5.
- iv) **Soil aeration:** The nitrifying bacteria are anaerobes and hence require sufficient oxygen supply.
- v) **Soil moisture:** The rate at which nitrification proceeds in a soil is governed to a marked extent by the water content being retarded by both very low or very high moisture content.
- vi) **Temperature:** Very low nearer freezing and increases rapidly up to 35°C.
- vii) **C : N ratio:** when organic residues with wide C : N ratio are added, general purpose decay organisms are dominant and nitrifiers become inactive.
- viii) **Pesticides:** Nitrifying organisms are quite sensitive to some pesticides.

Fate of nitrate nitrogen

Nitrate supplied in commercial fertilizers or produced by nitrification of ammonium may be:

Absorbed by the plants.

Utilised by soil microorganisms.

Lost through excess water by leaching because of its high mobility.

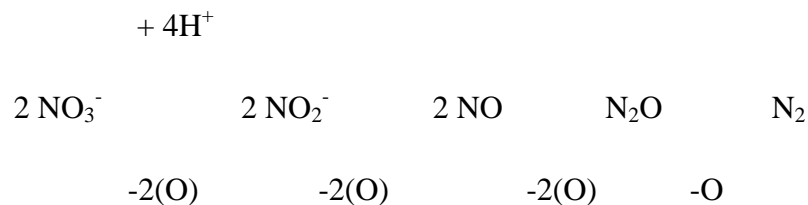
Escapes from soil in volatile condition through nitrate reduction referred to as denitrification.

Leaching losses of nitrate nitrogen:

Leaching loss of nitrogen from the soil is a loss from the soil-plant system and causes lower efficiency of applied nitrogen. It may vary from 2 to 50 % of applied N. Of the total leaching loss, more than 90 % is in the form of NO_3^- as mostly nitrate ions are present in soil solution because of the reason that the anion exchange capacity of the soil is much less than cation exchange capacity. Therefore, its movement is related to the movement of water in the soil. The magnitude of leaching loss of nitrogen depends on soil texture, hydrological condition, water table depth, permeability and hydraulic conductivity of soil. Leaching loss can be reduced by increasing water holding capacity through organic matter addition, split application of fertilizer N, controlled irrigation and by using nitrification inhibitors like N – serve, slow release N fertilizers like neem coated urea, sulphur coated urea.

Denitrification :

Denitrification is a process limited to anoxic soils in which bacterial reduction of NO_3^- and NO_2^- takes place leading to the release of NO , N_2O and N_2 gases. When soils become water logged, oxygen is excluded and anaerobic decomposition takes place. Some anaerobic organisms have the ability to obtain their oxygen from nitrates and nitrites with the accompanying release of nitrous oxide and nitrogen. The most probable biochemical pathway leading to these losses is indicated as



Facultative anaerobic bacteria belonging to the genera *Pseudomonas*, *Bacillus denitrificans* and *Paracoccus* are responsible for this. Autotrophs like *Thiobacillus denitrificans* also brings about denitrification.

Nitrification inhibitors: Several products have been developed with the purpose of slowing the release and/or nitrification of applied N to synchronise the supply of N with the crop demand and consequently decrease nitrogen losses via leaching and / or denitrification. These chemicals

restrict the growth of *Nitrosomonas* and keep nitrogen in NH_4^+ form.

Natural nitrification inhibitors Neem cake (*Azadiracta indica*) Karanj cake (*Pongamia glabra*)
Neem oil and nimin

Chemical nitrification inhibitors

N - serve or nitrapyrin (2 chloro – 6 tri chloromethyl pyridine) DCD (Dicyandiamide)

AM (2 amino, 4 chloromethyl pyrimidine)

ATC (4-amino 1,2, 4 triazole) Sulphathiozole

Thiourea Hydroquinone

Calcium carbide (CaC_2)

Phenyl phosphorodiamidate (PPD)

However, in India the use of such chemicals to retard nitrification is limited due to the high costs involved.

Nitrogen immobilization

Immobilisation of nitrogen is the reverse of mineralisation and it occurs when large quantities of low nitrogen crop residues with wide C:N ratio (>30:1) such as coconut coir or cereal straw begin decomposing in soil, the high amounts of carbohydrates in such residues cause the microbial population to build up quickly. As new cells are formed, nitrogen and other essential elements from soil are used to build protoplasm. This leads to a decrease in the levels of inorganic nitrogen for crops. A shortage of nitrogen can be avoided in such situations by supplying enough fertilizer nitrogen to compensate for immobilization and to meet the crop requirements. This lockup of inorganic N of soil is temporary and slowly will be released after mineralization.

Factors affecting phosphate fixation in soil

Factors affecting P fixation in soils

1. **Clay minerals:** The main seat of P fixation in soils rests on the clay fraction. The more the surface area exposed with a given type of clay, the greater is the tendency to retain phosphorus.
2. **Type of clay:** Phosphorus is retained to a greater extent by 1:1 than by 2:1 clays. Soils high in kaolinitic clay will fix larger quantities of added P due to more AEC.

3. **Hydrous metal oxides of iron and aluminium:** In soils with significant amounts of iron and aluminium oxides, the P fixing capacity is larger.
4. **Amorphous colloids:** In Andisols, due to the presence of large quantities of amorphous colloids like allophanes with large negative charges which are balanced by aluminium cations, the phosphate becomes fixed to these aluminium ions.
5. **Calcium carbonate:** Calcium carbonate precipitates phosphates to form insoluble apatites. The activity of P will be lower in those soils that have a high Ca^{2+} activity.
6. **Soil pH :** Adsorption of P by iron and aluminium oxides declines with increasing pH.
7. **Organic matter:** High organic matter content decreases P fixation.
8. **Temperature:** The rise in temperature generally enhances P fixation.
9. **Over liming:** Over liming increases P fixation by forming more insoluble Ca-P compounds.

Methods to reduce P fixation

1. **Organic matter addition:** Incorporation of organic residues into soil influences the reactions of phosphates and its availability to plants. Organic matter counteracts the effect of CaCO_3 . It also reduces P sorption by soil. Addition of organic matter also increases P concentration in soil solution through mineralization of organic P and solubilisation of native soil P compounds. This effect is more pronounced at higher moisture level. During decomposition of organic matter various organic acids are produced which solubilize the phosphates and other P bearing minerals and thereby lower the P – fixation.

The reason is

1. By formation of phospho - humic complexes that are easily assimilated by plants.

Through the mobilisation of the phosphate by humate ion by anion exchange

2. By forming a coating on sesqui oxide particles by humus as a protective cover which otherwise fix P.

2. **Placement of fertilizers:** The finer the soil texture, the greater is the retention of added P

due to increased speed of reaction with surface area of contact. If finely divided fertilizer P is added to a soil by applying through broadcast the phosphate is exposed to a greater amount of surface, hence more fixation takes place. While band placement reduces the surface of contact between the soil and fertilizer with consequent reduction in the amount of fixation.

3. **Role of mycorrhiza** : Certain mycorrhizal fungi known as VAM colonize plant roots and through this association help the plant to absorb more P.
4. **Role of P solubilising microorganisms**: P solubilising bacteria like *Bacillus megatherium* and *Pseudomonas striatus*; or fungal species namely *Aspergillus awamori* are reported to enhance the availability of fixed P and reported to add 30 – 35 kg P₂O₅ ha⁻¹ under ideal conditions.
5. **Liming of acid soils**: About one- third of Indian soils are acidic in reaction. The beneficial effect of liming of these acid soils is due to the release of fixed P that was held with iron, aluminium oxides & hydroxides.

Quantity– Intensity relationships Schofield (1955) divided the measurements

- i) **Intensity of supply**: Which indicates the soil solution phosphate and is measured by phosphate potential.
- ii) **Quantity factor**: rich indicates the total quantity of P in the soil. This pool supplies P to the soil solution pool (intensity) when P is taken up by plants.

In a limited range of P concentration where Q/I relationship is linear, the slope of the curve is given by which is referred to as phosphate buffering capacity or simply capacity, which indicates the resistance of soil to a depletion in quantity of P. For a given value of intensity, the quantity values are higher for fine textured soils than coarse textured soils. Availability of P to plants is controlled by the mutual interplay of the three factors viz., quantity, intensity and PBC. Hence, in clay soils depletion is less than sands, hence can supply P to the crops for longer period.

Functions of phosphorus in plants:

Phosphorus is the second most abundant mineral in human body making up for more

than 20 % of body minerals. It is largely absorbed by the plant roots as dihydrogen orthophosphate ion (H_2PO_4^-). In normal P sufficient plants, P content varies from 0.1 to 0.4 per cent by weight.

The following are the functions of phosphorus in plant system

1. Constituent of nucleoproteins, phytins and phospholipids.
2. Essential constituent of number of enzymes -important in energy transfer.
3. Essential for cell division and development.
4. Stimulates root development and growth.
5. Responsible for early establishment of seedlings.
6. Strengthens the straw and decreases lodging.
7. Brings about early maturity.
8. Counteracts the effect of excessive nitrogen.
9. Increases grain to straw ratio.
10. Improves the quality of food grain.
11. Increases rhizobial activity, increases the formation of root nodules thus helping in more N - fixation.

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

P deficiency results in

The production of dark green color leaves.

Severe restriction of root growth.

Thin, erect and spindly plants with sparse and restricted foliage.

suppressed lateral bud production.

bluish green foliage, and under continued deficiency the older leaves become bronzed or develop reddish purple tip or leaf margins.

Toxicity symptoms

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

Correction of deficiency

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

1. Single Super Phosphate (SSP) contains 16 to 22% P_2O_5
2. Rock phosphate contains 30-38 % P_2O_5
3. Triple Super Phosphate contains 46 % P_2O_5
4. Diammonium phosphate contains 46 % P_2O_5
5. Monoammonium phosphate contains 52 % P_2O_5
6. Basic slag contains 10-20 % P_2O_5

Factors affecting potassium fixation – Quantity and intensity parameters – Luxury consumption – Functions and deficiency symptoms – corrective measures

Factors affecting K-fixation

1. Clay minerals: K fixation is controlled mainly by clay minerals, with both their quantity and nature being important. Illite, weathered mica, vermiculite take part in K fixation but 1:1 type of clays such as kaolinite do not fix potassium.

2. Soil reaction: K fixation capacity can be reduced by the presence of Al^{3+} and Al-hydroxide cations.

3. Cation Exchange Capacity (CEC): Fine textured soils have a higher CEC and hold more exchangeable K.

4. Concentrations of added K: Increasing the concentration of K^+ in soils with high fixing capacity encourages greater fixation.

5. Wetting and drying: Soils with high exchangeable K^+ on drying will result in fixation due to air drying.

6. Freezing and thawing: of moist soils may release fixed K.

7. Sub soil K and rooting depth: Exchangeable K varies with depth

8. Soil temperature: Higher temperature favors dehydration and

9. Ca and Mg (exchangeable cations): The size of K^+ and other ions that would replace K is important in K fixation. The cations of smaller size of the hydrated ions can easily enter into clay lattices and replace some of the fixed potassium.

Quantity and intensity parameters

The concept of intensity, quantity and buffering power proposed by Beckett (1964) are useful in measuring the potassium supplying power of soils.

Intensity factor is a measure of K in soil solution that is immediately available for absorption by plants. Since this absorption is influenced by the activity of other cations like Ca^{2+} and Mg^{2+} in the soil solution, the potassium activity ratio (AR^k) is used in place of K concentration alone to indicate the intensity factor.

$$AR^k = \frac{[K^+]}{[Ca^{2+} + Mg^{2+}]}$$

Quantity factor is a measure of the capacity of the soil to maintain the level of K in soil solution over a long period or over the duration of crop growth. The capacity is mainly due to the exchangeable K

The slope of the curve indicates the potential buffering capacity, which indicates how the K level in the soil solution (intensity) varies with the amount of labile form (quantity)

$$PBC = \frac{\Delta Q}{\Delta I}$$

The wider the ratio, the more buffered is the soil. Soil having smectitic clay have more PBC, than having kaolinite.

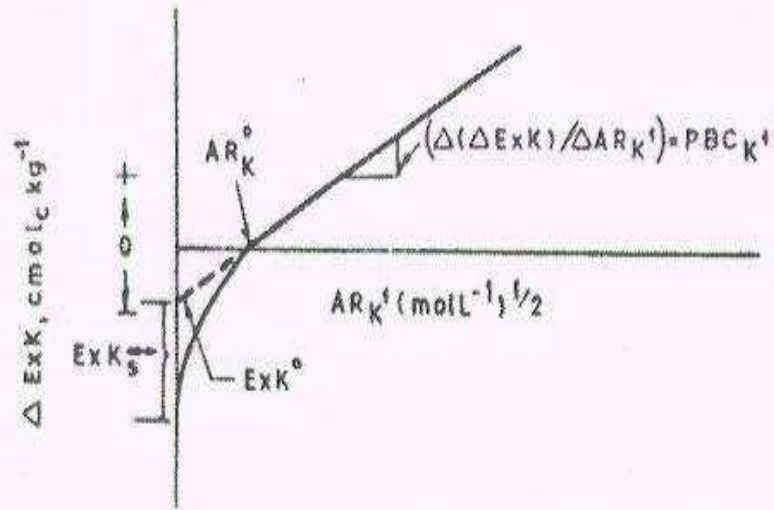
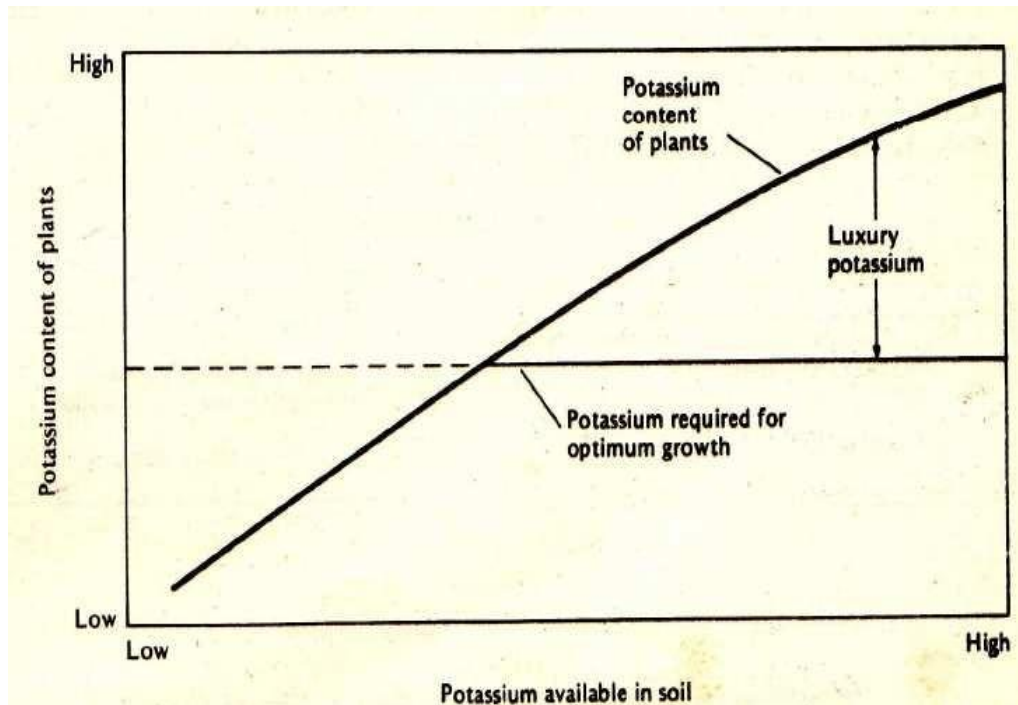


Figure 3. A typical quantity/intensity (Q/I) relations (adapted from Evangelou, 1994)

Luxury consumption: Some crops tend to absorb and accumulate potassium for in excess of their needs if it is present in sufficiently large quantities in the soil. This tendency is termed luxury consumption because the excess K absorbed does not increase crop yields to any appreciable extent. Wasteful luxury consumption occurs especially with forage crops.



Functions: K is absorbed by the plant as K^+ . Its concentration in healthy tissue varies from 1-5 %. Potassium is a unique element that plants can accumulate it in abundant amounts without exhibiting any toxicity symptoms. This behaviour is referred to as luxury consumption. Potassium plays a regulatory role in plant metabolism. Potassium is not a component of any organic compound in plants.

- It regulates the opening and closing of stomata.
- Plays a major role in transport of water and nutrients throughout the plant in xylem.
- It improves drought tolerance.
- Neutralizes organic anions and other compounds and maintains the pH of cytoplasm in the range of 7-8.
- Activates > 60 enzymes, including starch synthetase, K is responsible for the activation of nitrate reductase enzyme.
- Enhances crop quality, shelf life of fruits and vegetables.
- Reduces lodging of crops, enhances winter hardiness.
- Imparts disease resistance.

Deficiency symptoms

1. Potassium deficiency does not manifest immediately in the form of visible symptoms.

First growth rate decreases and later deficiency symptoms appear.

2. Deficiency symptoms first develop on the older leaves.
3. Chlorosis along the margins followed by scorching and browning of tips of older leaves which gradually progresses inwards giving burning appearance.
4. Slow and stunted growth of the plant and crop lodging.
5. Shrivelled fruits and seeds.
6. Reduced crop yields without the appearance of definite symptoms; the phenomenon is called hidden hunger.
7. Decrease in resistance to certain plant diseases
8. Decrease in the quality of fruits and vegetables.
9. Potassium deficiency disturbs the overall physiological activity within the plant system by altering the activities of enzymes like invertase, catalase in crops like sugarcane.

Correction measures

Potassium chloride or muriate of potash constitutes 99% of usage of K fertilizer and potassium sulphate accounts for 1%. Muriate of potash contains 60% K_2O or 50% K and sulphate of potash contains 50 % K_2O or 41.5% K.

Some crops are sensitive to high amounts of potassium chloride. These include tobacco, grapes, cotton, fruit trees, sugarcane, potatoes, tomatoes, straw berries, onion and cucumber. Oil palm and coconut on the contrary appear to be chloride loving crops.

Generally, potassic fertilizers are applied as basal dose, but for light textured soils, split application is advocated. In Andhra Pradesh split application of N and K are recommended for light soils.

Potassium nitrate containing 44% K_2O (37% K) and 13% N is preferred for spraying on fruit trees and horticultural crops. Spraying of KNO_3 during winters (*rabi* season) to impart cold hardiness is also in practice by the farmers in Andhra Pradesh.

Predisposing factors for occurrence of micronutrient deficiencies in soil and plants

- i) **Parent material:** The soils whose parent material originally contain low amounts of micronutrients are most likely to show micronutrient deficiency under leaching and intensive cropping.

- ii) **Soil pH:** Acid soil conditions are most conducive for Mo deficiency. Similarly, high pH soils such as sodic soils show Zn, Fe, Mn and Cu deficiency. Over liming of acid soils also causes deficiency of micronutrient cations. In acid sulfate soils micronutrient toxicity limits crop growth.
- iii) **Land leveling and shaping:** Land leveling and shaping removes the fertile top soil in which micronutrients are concentrated.
- iv) **High yielding varieties:** HYV require more nutrients depleting the nutrients from soil causing their deficiencies.
- v) **Imbalanced nutrient application:** High doses of macronutrient application induces micronutrient deficiencies.
- vi) **Soil conditions:** Water logged condition reduce the availability of Zn and Cu and increase availability of Fe and Mn.
- vii) **Organic matter:** Organic compounds like humic and fulvic acid form organo - metallic complexes held as insoluble complexes. But some organic ligands can keep micro nutrient cations as soluble chelates and those are plant available.
- viii) **CaCO₃:** More CaCO₃ leads to less availability of Fe, Mn, Zn, and Cu; and increases Mo availability.
- ix) **Soil texture:** Boron is available in more amounts in coarse fraction, but fixed in fine textured soils.
- x) **Clay content:** Montmorillonite adsorbs more Zn and Cu.
- xi) **Fertilizers:** Fertilizers containing macronutrients when applied to soil induce the deficiency of micronutrients. Basic nitrate salts reduce iron availability.
- xii) **Interactions with macronutrients:** Interaction is defined as the influence of an element upon another in relation to crop growth. Negative interaction is observed between P and Zn leading to P induced Zn deficiency.