Functional Roles-based Classification

S.No	Group	Nutrients
1	Structural Components	C, H, O, N, P and S
2	Enzyme Activators	K, Ca, Mg, Mn and Zn
3	Redox Reagents	Fe, Cu, Mn and Mo

Ballast Elements – ***Silicon (Si)*** and ***Aluminium (Al)***, second and third most abundant elements in the earth crust don't find role in plant nutrition, as yet are present in significant amounts in plant tissues. These have been termed as "***Ballast Elements***". These elements ***impart physical strength to plants***.

Some important points about nutrients

1. ***Si (Silicon) and Na (Sodium)*** have been listed as the ***beneficial elements***, particularly for ***paddy rice***.
2. ***Molybdenum is*** structural component of ***nitrate reductase*** and ***nitrogenase*** enzymes associated with nitrogen metabolism.
3. Co is the only element missing on the essential nutrients list from the "***Irving-Williams stability series***" [This series refers to the relative stabilities of complexes formed by a metal ion. For high-spin complexes of the divalent ions of first-row transition metals, the stability constant for the formation of a complex follows the order: Mn(II) < Fe(II) < Co(II) < Ni(II) < Cu(II) > Zn(II)

Functions and Deficiency Symptoms of Nutrients

1. Nitrogen

1. Nitrogen is **vitally important** plant nutrient.
2. **Essential constituent of proteins,** amino acids, nucleic acids, nucleotides, enzymes, hormones, vitamins, alkaloids and phosphatides.

3. Nitrogen is the **"basic constituent of life".**
4. It is the **integral part of chlorophyll.**
5. The basic unit of chlorophyll's structure is the porphyrin ring system, composed of four pyrrole rings, each containing one nitrogen and four carbon atoms. A single magnesium atom is bonded in the centre of each porphyrin ring.
6. Responsible for transfer of genetic code to the off-springs.
7. Improves quality of leafy vegetables and fodders.
8. Nitrogen fertilization ***improves the protein quality*** of the food grains.

[**NOTE:** Nitrogen is absorbed by plant roots as NO_3^- ion and in the case of rice, as NH_4^+ ion also. Because of the occurrence of wide-spread deficiencies, N is often referred to as the "***universally-deficient nutrient***" element in crop production and frequently creates serious nutritional problems]

Deficiency Symptoms

1. Yellowing or ***chlorosis*** of the plant leaves
2. Reduction in flowering, crop yields and lower protein content
3. Typical nitrogen deficiency symptoms are described lucidly by ***Agarwala and Sharma*** (1976). "***Paling***" starts from the older leaves and spreads towards younger, first appears towards the leaf apex or towards the anterior leaf margins and spreads gradually the base of the leaves. As paling and pigmentation become severe, the affected tissues become dry necrotic, a condition sometimes referred as "***firing***". Root growth gets restricted and roots become fibrous.

2. Phosphorus (P)

1. Phosphorus has a great role in ***energy storage and transfer.***
2. Closely related to ***cell division and development.***

3. Phosphate compounds act as ***energy currency*** within the plants.
4. Stimulates early ***root development*** (Root developer).
5. It gives rapid and vigorous start to plants, strengths to straw and decreases lodging tendency.
6. Brings ***early maturity*** of crops.
7. Transfer ***genetic characters from one generation to the next.***
8. Essential ingredient for ***Rhizobium*** bacteria to convert atmospheric N (N_2) into the ammonium (NH_4^+) form usable by plant. Being an energy source it also influences nodule development of plants.
9. Improved ***drought and salinity resistance.***
10. Important for flower/seed formation.

[**NOTE:** ***Phosphorus*** stored ***in seeds*** in the form of "***phytin***" and ***calcium*** present in seeds as ***calcium phytate.***]

Deficiency Symptoms

1. In maize and some other grass species, purple discolouration of the leaves or leaf edges appears and this ***purple discolouration*** due to "***anthocyanin***" accumulation.
2. Development of lateral bud suppressed.

[**NOTE:** The ATP and ADP are the energy currency of the plants as ***ATP stores 12 kcal energy per mole*** contained in two pyrophosphate bonds between three P molecules]

3. Potassium

1. It plays major role in catalysing activities of ***more than 60 enzymes*** and ***starch synthetase*** is prominent among them.
2. It is responsible for the activation and synthesis of protein-forming nitrate reductase enzyme.

3. It regulates the ***opening and closing stomata***.
4. It plays a major role in the ***transport of photosynthates through phloem*** to other parts of the plant for utilization and storage.
5. Increased ***both disease and drought resistance*** of crops.
6. Enhances ***winter hardiness to*** legumes and other crops.
7. Potassium plays a significant role in enhancing ***crop quality*** and that is why potassium also called "***quality element***".
8. Helping to stabilize pH between 7 and 8 which is optimum for most enzyme reactions.
9. Plays a major role in ***transport of water and nutrients*** throughout the plant in the xylem.
10. Potassium ***reduces lodging and water loss.*** ***(ARS & NET 2017)***
11. ***Translocation of assimilated sugars from leaves*** is greatly reduced in potassium deficiency plants.
12. ***Osmotic regulation*** is another function of potassium.

Deficiency Symptoms

1. Chlorosis along the leaf margins is followed by ***scorching and browning*** of tips of older leaves which gradually progress inwards.

[NOTE: *Luxury consumption* and ***Hidden hunger*** both are related to potassium element]

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.***

Hidden Hunger – Sometimes serious yield reductions occur in crop plants without the appearance of deficiency symptoms.

[**NOTE:** Hidden hunger occurs not only for potassium but also for other nutrient elements]

[**NOTE: Potassium is not a structural component of the plant**]

4. Calcium

1. As calcium pectate, it is constituent of the cell wall. It maintains the integrity of the cell membranes.
2. Facilitates the **growth of meristems** and functioning of the root tips.
3. It plays **role in mitosis** (cell division) and helps **maintain the chromosome structure.**
4. High supply of Ca may be a pre-requisite for making symbiotic leguminous plants susceptible to infection by ***Rhizobium***.
5. It neutralizes the charge on acidic molecules of phosphoric acid and organic acids *viz.* Citric acid, maleic acid, oxalic acid etc.
6. It protects the root cells against ion imbalance, low pH and toxic ions like Al^{+3}.

Deficiency Symptoms

1. **Calcium is immobile in plant** hence deficiency symptoms appear on the younger structures.
2. Calcium deficient leaves become cup-shaped and crinkled and the terminal buds deteriorate with some break-down of petioles.
3. **Blossom end rot in tomato.**
4. **Bitter pit in apple.**
5. **Tip hooking in cauliflower**

6. Blackheart in celery
7. Cavity spots in carrot
8. Water core of apple
9. Leaf tip burn in cabbage and lettuce

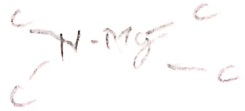
[**NOTE:** Calcium could easily be termed as "***reclamation nutrient***" as its sulphate salt (Gypsum – $CaSO_4$. $2H_2O$) is used for reclamation of the sodic soils and the oxide/hydroxide/carbonate salts [CaO, $Ca(OH)_2$, $CaCO_3$] are used for counteracting soil acidity]

5. Magnesium

1. Magnesium is ***constituent of chlorophyll as Mg-porphyrin with one atom of Mg bound to four pyrrole rings***. Role of Mg^{+2}, being the coordinating ion in the chlorophyll molecule, was discovered by ***Richard Willstatter***, who received the Nobel Prize in Chemistry in 1915 for the purification and structure of chlorophyll.
2. Magnesium is the ***powerhouse*** behind photosynthesis in plants.
3. Without Mg chlorophyll cannot capture sun energy that is needed for photosynthesis to occur and the reaction $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$ can't be driven to completion.
4. Mg is required to give leaves their ***green colour.***
5. It activates critical enzymes, including ***ribulosbiphosphate carboxylase*** (RuBisCO)and ***phosphoenolpyruvate carboxylase*** (PEPC) – both having a role in carbon fixation.
6. Essential ***constituent of polyribosomes.***
7. It promotes uptake and ***translocation of phosphorus and movement of sugars*** within the plants.

8. Mg brings about significant ***increases in the oil content*** of several crops.
9. Mg involved in ***carbohydrate metabolism*** and ***synthesis of nucleic acids.***

[**NOTE:** *The porphyrin ring contains the N, where as Mg is bonded at the centre of the porphyrin rings*]



Deficiency Symptoms

1. Mg deficiency symptoms manifest themselves in terms of ***intervenial chlorosis*** and streaked or patchy effects ***on older leaves.***
2. In many species, shortage of Mg^{+2} results in ***intervenial chlorosis*** of the leaf, in which only ***veins remain green.***
3. ***Grass tetany*** is an Mg-deficiency related ***nutritional disorder*** common in cattle grazing on Mg-deficient pastures well fertilized with potassium.
4. Sand drawn in tobacco

6. Sulphur

1. Sulphur is the essential constituent of S-containing amino acids, ***viz.*** ***cysteine*** ($C_3H_7NO_2S$), ***cystine*** ($C_6H_{12}N_2O_4S_2$) (two molecules of cysteine upon getting oxidized to yield one molecule of cystine) and ***methionine.***
2. All nitrogenases have an iron (Fe) and sulphur-containing cofactor that includes an iron-sulphur cluster at the active site, in most of the proteins, this Fe-S cluster also contains Mo.
3. As a constituent of Ferridoxin-containing nitrogenase, sulphur takes part in the biological nitrogen fixation (BNF) and other electron transfer reactions.
4. Several biologically active compounds like vitamins – ***thiamine and biotin,*** lipoic acid, acetyl co-enzyme A and glutathione contain S as an essential part.
5. It is involved in the synthesis of ***glucosides in mustard oil.***

6. It plays a major role in improving the ***oil quality in oilseed crops.***
7. Although not a constituent, sulphur is required for the ***synthesis of chlorophyll.***

Deficiency Symptoms

1. Crop plants having N: S ratios more than 16:1 also can be suspected to be deficient in S.
2. Sulphur deficiencies first appear on the younger growths as S is immobile in the plants.
3. ***Brassicas*** are most susceptible for S-deficiency, the lamina is restricted, leaves show ***cupping*** owing to the curling of the leaf margins and arresting of the growing points.
4. "***Tea yellow disease***" in tea.

7. Chlorine

1. Chlorine plays a major role in ***Osmoregulation*** (cell elongation, stomatal opening) and charge compensation in higher plants.
2. It is essential for ***photosynthesis,*** where it is involved in the evolution of oxygen
3. It acts as a cofactor in Mn-containing water splitting enzyme of photosystem II.
4. Chlorine in abundance suppresses the plant diseases, *viz.* Grey leaf spot in coconut palms, take – all and common root rot in wheat, common root rot and ***Fusarium*** root rot in barley, stalk rot in corn, stem rot and sheath blight in rice, hollow heart and brown centre in potatoes, ***Fusarium*** yellows in celery and ***downy mildew in millet.***

Deficiency Symptoms

1. Wilting, twisting and curling of leaves.

[NOTE: *Deficiency symptoms of chlorine are similar to Mn deficiency*]

8. Iron

1. Iron is a constituent of two groups of proteins, *viz.* (a) ***Heme proteins containing Fe porphyrin complex as a prosthetic group***: Cytochrome oxidase, catalase, peroxidise, leghaemoglobin, and (b) ***Fe-S proteins in which Fe is coordinated to the thiol group of cysteine or to inorganic S***: Ferredoxin.
2. It plays an essential role in the ***nucleic acid metabolism.***
3. It is necessary for ***synthesis and maintenance of chlorophyll*** in plants. ***(ARS Mains 2017)***

Deficiency Symptoms

1. ***Intervenial chlorosis on younger leaves*** with leaf margins and ***veins remaining green.*** Under conditions of severe deficiency, growth cessation occurs with the whole plant turning ***necrotic.*** ***(ARS Mains 2017)***
2. **Lime induced chlorosis** ***(ARS Mains 2015)***
3. **Akiochi in rice**

[NOTE: Akiochi disease in rice caused due to toxicity of H_2S and deficiency of Fe] ***(ARS & NET 2015)***

9. Boron

1. Boron is responsible for the cell wall formation and stabilization, lignification and xylem differentiation.
2. Boron is involved in the ***movement of Ca*** in the plant.

3. It plays major role in transport of water, nutrients and organic compounds including sugars to the actively growing portions in plants.
4. It increases flower production and retention, pollen tube elongation and germination and seed and fruit development.
5. It imparts ***drought tolerance*** to crops. Regular boric acid sprays helps in mitigating harmful effects of drought.
6. It plays a role in ***pollen germination and pollen tube growth.***
7. It facilitates transport of K in guard cells as well as stomatal opening.
8. Boron regulates ***carbohydrate metabolism.***

Deficiency Symptoms

1. Boron deficiency symptoms become conspicuous ***on the terminal buds or the youngest leaves***, which become discoloured and may die under acute conditions of B- deficiency.
2. **Internal cork of apple** ***(ARS & NET 2015)***
3. Uneven thickness peel, gummy deposits and lumpy fruit in citrus
4. Brown heart in root crops

[**NOTE:** Black heart of potato due deficiency of oxygen]

5. Heart rot of sugar beet
6. Heart rot of mangold
7. **Browning or hollow stem of cauliflower**
8. **Top sickness of tobacco**
9. Cracked stem of celery (Increased diameter of stem and petioles)
10. Fruit cracking

11. Crown rot of sugar beet
12. Hard fruits
13. Hen and chicken disease in grapes
14. Brown heart of radish
15. Crown chocking of coconut
16. Rotting of fruit

10. Manganese

1. Mn is integral ***component of water splitting enzyme*** associated with photosystem II, it catalyses the biochemical reaction of water oxidation ($2H_2O \rightarrow 4e + 4H^+ + O_2$). Because of this, Mn deficiency is associated with adverse effects on photosynthesis and O_2 evolution.
2. It is a ***constituent of superoxide dismutase (Mn-SOD)*** which being present in mitochondria, peroxisomes and glyoxysome, protects cells against the deleterious effects of superoxide free radicals.
3. Being a ***constituent of nitrite reductase and hydroxylamine reductase*** enzymes, Mn is linked with nitrogen assimilation in plants.
4. Mn has a ***role in tricarboxylic acid cycle (TCA)*** in oxidative and non-oxidative decarboxylation reactions
5. Mn plays a role in ***maintenance of chloroplast membrane structure.***
6. Mn helps in ***chlorophyll formation.***

Deficiency Symptoms

1. ***Grey speck*** in oats
2. Speckled yellow of sugarbeet

3. Marsh spots in pea
4. ***Pahala*** blight in sugarcane *(ARS Mains 2017)*
5. Frenching in tung trees
6. ***Little leaf in apple***

[**NOTE:** Generally little leaf symptom related to zinc deficiency but in apple it is due to Mn deficiency]

11. Zinc

1. Zinc is a constituent of 3 enzymes – ***carbonic anhydrase***, ***alcoholic dehydrogenase*** and ***super oxide dismutase***.
2. Zinc is involved in the ***synthesis of indole acetic acid (IAA)***, metabolism of gibberellic acid and ***synthesis of RNA***.
3. Zinc promotes synthesis of cytochrome C
4. Zinc influences translocation and transport of P in plants.

[**NOTE:** P x Zn having generally negative interaction which is called "***antagonism***"]

5. Zinc involved in ***auxin metabolism*** like, ***tryptophan synthetase***, tryptamine metabolism.
6. Zinc stabilizes ribosomal fractions.

Deficiency Symptoms

1. ***Khaira disease*** of rice – deriving it's from dark reddish brown pigmentation of the leaves of the affected plants *(ARS & NET 2017)*
2. **White bud in maize** and sorghum
3. **Little leaf in cotton, brinjal and mango**

4. Mottle leaf or Frenching of citrus
5. Rosette disease of apple
6. Fern leaf of potato

Khaira Disease – Khaira disease in India discovered by ***Dr. Y L. Nene*** at GBPUAT, Pantnagar. As described by ***Agarwala and Sharma*** (1976), first symptoms of zinc deficiency appear in ***3 or 4 week old seedlings*** when young leaves develop ***reddish brown pigmentation***. The pigmentation first appears in the middle of the leaves, then intensifies and spreads over the entire lamina.

[**NOTE:** "*Bronzing*" in rice caused due to toxicity of Al]

12. Copper

1. Cu is imparting ***disease resistance*** to the plants
2. Enhances ***fertility of male flowers.***
3. Cu indirectly affects ***nodule formation. (JRF 2016)***
4. It acts as "***electron carrier***" in enzymes which bring about oxidation-reduction reactions in plants.

Deficiency Symptoms

1. Male flowers sterility
2. Delayed flowering and senescence
3. **White tip**
4. Reclamation disease
5. **Dieback in citrus**
6. Excess gumming

7. **Exanthema in citrus**
8. **Empty glumes in wheat**
9. Stem melanosis in wheat
10. Gummosis

13. Molybdenum

1. Mo is structural ***component of nitrogenase enzyme.*** This enzyme has MoFe protein and the FeS protein as its structural components. Nitrogenase catalyses the biological nitrogen reduction of N_2 to NH_3 as per following equation.

$$N_2 + 8e^- + 8H^+ + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16Pi$$

2. Requirement of Mo is particularly high in nodulated legumes.
3. ***Nitrate is reduced by nitrate reductase (NR) enzyme in cytoplasm*** by transfer of electrons from Mo to NO_3^-. ***(SRF 2015)***

[**NOTE:** Owing to close relationship between Mo supply, nitrate reductase activity (NRA) and plant growth, ***NRA has been used as indicator of status of Mo in plants***]

4. Mo affects the formation and viability of pollens and development of anthers.

Deficiency Symptoms

1. Chlorotic mottling in cauliflower
2. ***Whip-tail*** in cauliflower
3. Cupping in cauliflower
4. Scald in beans

14. Nickel

1. Ni is ***associated with nitrogen metabolism*** by way of influencing ***urease activity***.
2. In free-living *Rhizobium*, adequate Ni supply ensures optimum hydrogenase activity.
3. It facilitates transport of nutrients to the seeds or grains.

Deficiency Symptoms

1. Leaf chlorosis and leaf tip necrosis in cowpea.

[NOTE: Fe – Component of nitrogenase, nitrite reductase and nitrate reductase

Mo – Component of nitrogenase and nitrate reductase

Mn – Component of nitrite reductase] *(ARS & NET 2017)*

S. No	Deficiency symptoms	Nutrient
1	Symptoms appearing first on older leaves	N, P, K, Mn and Mg
2	Symptoms appearing first on younger leaves	S, Fe, Mn, Cu and B

[NOTE: Intervenial chlorosis on younger leaves –Fe deficiency
Intervenial chlorosis on older leaves – Mg deficiency
Complete intervenial chlorosis – Mn deficiency]

Growth Laws

1. Liebig's Law of Minimum – Law of Minimum states that "*Even if all but one of the essential possible elements be present, the absence of that one will render the crop barren*".

[NOTE: In India nitrogen is most limiting factor in low land and upland conditions. So the most deficient macro nutrient in Indian soils is N and micro nutrient is Zn (Boron is second place after Zn)]