THE PLANT NUTRIENTS

Macro Nutrients

- Carbon (C)
- Hydrogen (H)
- Oxygen (O)

Used in exceptionally large quantities

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)

Used in large quantities

Secondary Nutrients

- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

Used in moderate quantities

Micronutrients

- Boron (B)
- Chlorine (Cl)
- Cobalt (Co)
- Copper (Cu)
- Iron (Fe)
- Manganese (Mn)
- Molybdenum (Mo)
- Nickel (Ni)
- Silicon (Si)
- Sodium (Na)
- Zinc (Zn)
- Vanadium (Va)

Used in small quantities

Carbon, Hydrogen and Oxygen represent 90-96% of the dry matter of all plants. These elements are supplied by atmospheric carbon dioxide and water. The plant obtains the remaining 4-10% from the soil and/or fertiliser inputs.

A more detailed table listing approximate concentrations of nutrient elements required for healthy plant growth is as follows.

Element	Concentration in dry matter ppm	%
Hydrogen	60 000	6.0
Carbon	420 000	42.0
Oxygen	480 000	48.0
Nitrogen	14 000	1.4
Potassium	10 000	1.0
Calcium	5 000	0.5
Magnesium	2 000	0.2
Phosphorus	2 000	0.2
Sulfur	1 000	0.1
Chlorine	100	
Iron	100	
Boron	20	
Manganese	50	
Zinc	20	
Copper	6	
Molybdenum	0.1	
Sodium	trace	
Cobalt	trace	
Silicon	trace	

**Edwards D.G. (1971) Concepts of essentiality and function of nutrients*

In commercial agriculture the following elements are applied, when necessary, to improve crops.

Macronutrients	**Secondary Nutrients**	**Micronutrients**
Nitrogen (N)	Calcium (Ca)	Zinc (Zn)
		Iron (Fe)
Phosphorus (P)	Magnesium (Mg)	Manganese (Mn)
		Copper (Cu)
Potassium (K)	Sulfur (S)	Boron (B)
		Molybdenum (Mo)

NUTRIENT	FUNCTIONS IN THE PLANT	DEFICIENCY SYMPTOMS	CONDITIONS THAT REDUCE AVAILABILTY	SENSITIVE CROPS
Nitrogen (N)	• an essential element in all living systems • needed by all cells • occurs in the living substance (protoplasm) of cells • a major component of protein • a major component of chlorophyll which converts sunlight into plant energy • affects both yields and quality.	• lighter green or yellow coloured leaves (first evident in older leaves) – some plants eg. berries can develop red or orange colours • stunted growth • lower protein levels in pasture and grain • delayed maturity • decreased resistance to disease and/or insect attack • smaller fruit • lower yields • shorter storage life	▪ light or sandy soils where nitrate nitrogen is leached ▪ water logged soils ▪ soils with structural problems as a result of poor aeration ▪ mineral soils low in organic matter ▪ soils where nitrogen has been depleted by previous crops ▪ soils where the ammonium form has been applied to high pH soils (free ammonia)	All crops are sensitive to nitrogen deficiency
Phosphorus (P)	• necessary for proper cell division and the formation of new cells • photosynthesis • sugar and starch formation • energy transfer • carbohydrate transport.	• reduced growth – sometimes stunted and other times only evident from shortened internodes, smaller leaves and reduced shoot growth. • dark green colour in some crops • purple leaves in others eg. brassicas • reduced tillering in cereals • small misshapen fruit – can be pulpy with poor storage life • poor seed development	▪ soil with a pH less than 5.5 or more than 7.0 ▪ soil with a high clay content ▪ mineral soils low in organic matter ▪ soil with high levels of hydrous oxides of aluminum or iron ▪ soils where phosphorus has been depleted by previous crops	Cereals, maize, broccoli, cabbage, cucumber, lettuce, potatoes, soft fruits, tree fruits (particularly citrus) and tomatoes.

NUTRIENT	FUNCTIONS IN THE PLANT	DEFICIENCY SYMPTOMS	CONDITIONS THAT REDUCE AVAILABILTY	SENSITIVE CROPS
Potassium (K)	• aids photosynthesis and the functioning of chlorophyll • important for the formation and translocation of starches, sugars and fats • involved in protein formation • aids many enzyme actions • helps cells maintain their internal pressure • reduces wilting and respiration by maintaining the balance of salts and water in cells • improves crop quality • increases root growth and resistance to disease and drought • decreases lodging.	• light green to yellow older leaves which later develop marginal leaf scorch- different plants have their own visual deficiency symptoms • plant growth is retarded • lodging • disease resistance is reduced • stalks are weakened • seed and fruit is misshapen	▪ continuously cropped soils with low levels of organic matter ▪ soils without balanced fertiliser programs ▪ light sandy soils where potassium has been leached ▪ periods of drought ▪ prolonged periods of heavy rain ▪ some clay soils (eg. Krasnozems) ▪ soils in which deficiencies of phosphorus and molybdenum have been corrected ▪ heavily limed soil ▪ soils formed from parent material low in potassium	Apples, beans, berries, broccoli, citrus, cucurbits, grapes, legumes, lettuce, maize, nuts, passionfruit, peas, potatoes, rhubarb, stone fruit, sunflowers, tomatoes.
Calcium (Ca)	▪ necessary for the proper functioning of growing points particularly root tips ▪ forms compounds which strenghten cell walls ▪ aids in cell division and elongation ▪ neutralises organic acids ▪ aids in the proper working and permeability of cell membranes ▪ regulates protein synthesis and slows the aging process.	▪ terminal buds and root tips fail to develop normally. • lodging • stunted root systems • leaves of grasses do not open properly the tips of which stick to the next lowest leaf • soft fruit • senescent breakdown and poor storage life of fruit • internal and external disorders of many fruit and vegetables	• low pH soils. • where there is an unfavourable balance of calcium, magnesium and potassium in the soil (particularly heavy potassium inputs in sandy soils) • where high rates of nitrogen have been used	Tree crops, fruit and vegetables. Calcium is not easily translocated in plants, so a constant supply is required. This should be foliar applied and in fruiting crops be available from after flowering onwards.

NUTRIENT	FUNCTIONS IN THE PLANT	DEFICIENCY SYMPTOMS	CONDITIONS THAT REDUCE AVAILABILTY	SENSITIVE CROPS
Magnesium (M)	▪ the only mineral constituent of the chlorophyll molecule ▪ aids plants to form sugars and starches ▪ plays an important part in the translocation of phosphorus ▪ aids several plant enzymes to function.	• interveinal chlorosis beginning in the tips of older leaves. Veins remain green, the chlorotic areas change from yellow to brown (other colours in some plants). • leaves become brittle and necrotic and may drop prematurely • yield can be seriously reduced • cotton leaves develop a purplish – red colour between green veins • some varieties of black grapes and stone and pit fruit can develop interveinal red chlorotic areas • grass tetany in sheep and cattle • excessive premature fruit drop	• sandy acid soils – particularly in high rainfall areas • course textured soils in humid regions • cold wet conditions • soils where there have been heavy inputs of potassium • soils which have received repeated green manuring	Vines, pome fruit, stone fruit, citrus, maize, tomatoes, capsicums, broccoli, cauliflower, lettuce, potatoes, parsley, pumpkin and many others.
Sulfur (S)	▪ similar requirements to phosphorus in plants ▪ a constituant of several amino acids which are essential for protein production ▪ aids the activities of some enzymes and vitamins ▪ needed for chlorophyll formation ▪ deficiency adversely affects the oil content in some oil crops and the baking quality in wheat crops ▪ aids efficient nitrogen stabilisation ▪ needed for nodule formation in legumes	• generally very similar to nitrogen deficiency - a uniform pale green to yellow leaf but the difference is sulfur deficiency starts in the new leaves whereas nitrogen deficiency starts in the old leaves. • In legumes the nodules produced are smaller, pale rather than pink and reduced in number • deficiencies in field crops include poor low yielding plants, low protein and pale green and yellow leaves in wheat.	▪ soils low in organic matter that have been cropped for many years. ▪ acid sandy soils where sulphate has been leached - especially such areas with high winter rainfall.	Cotton, clovers, phalaris, barrel medic, lucerne, canola, wheat, barley, maize, sunflowers, soybean, navy beans, sorghum, oats and triticale.

NUTRIENT	FUNCTIONS IN THE PLANT	DEFICIENCY SYMPTOMS	CONDITIONS THAT REDUCE AVAILABILTY	SENSITIVE CROPS
Boron (B)	▪ plays a role in cell division, ▪ aids efficient translocation of calcium, ▪ protein synthesis, ▪ carbohydrate metabolism, ▪ pollen viability ▪ flower and fruit set and formation. ▪ Hormone formation	• thick, curled and brittle tissues – cracking and splitting, sometimes with gumosis • surfaces of leaf, petioles, stems and midribs develop cracks or a corky appearance • reduced flowering, seed set and fruit set. • Growth points can die forming multiple side shoots • Small misshapen fruit • Internal flesh disorders and cracking in fruit and vegetables	▪ high pH soils ▪ overlimed soils ▪ soils with high levels of nitrogen and/or calcium ▪ sandy soils that are easily leached ▪ soils with low organic content ▪ cold wet weather (especially following a long dry spell)	Cotton, barley, maize, oats, sorghum, sunflower, clover, lucerne, navy beans, soy beans, citrus, nuts, pome fruit, stone fruit, root crops and vegetables.
Copper (Cu)	▪ required for chlorophyll production ▪ helps with photosynthesis ▪ aids in the production of enzyme protein ▪ involved in several enzyme systems ▪ involved in several oxidation reduction reactions and the formation of lignins ▪ helps regulate water movement in plants. ▪ Required for seed production	• marginal chlorosis of young leaves sometimes necrotic tips (if severe) • twig dieback • sometimes necrotic and brown spots over leaf surface • reduced growth and yields	▪ soils with excess nitrogen and/or phosphorus ▪ high pH soils ▪ heavily limed soils ▪ soils that have had molybdenum applied ▪ peat and muck soils – high in organic matter ▪ leached acid soils ▪ alkaline and calcarious soils ▪ cold wet conditions (availability can often be delayed at spring time) ▪ soils with high concentrations of iron and manganese ▪ soils formed from parent materials low in copper	Cereals, maize, lucerne, citrus trees, carrots, lettuce and onions

NUTRIENT	FUNCTIONS IN THE PLANT	DEFICIENCY SYMPTOMS	CONDITIONS THAT REDUCE AVAILABILTY	SENSITIVE CROPS
Iron (Fe)	▪ necessary for the formation of chlorophyll ▪ aids in photosynthesis ▪ involved in the oxidation process that releases energy from starches and enzymes ▪ aids in the formation of proteins ▪ involved in the conversion of nitrate to ammonia in the plant. ▪ aids respiration.	• young leaves – interveinal chlorosis with green veins • later in season – yellowing of leaves (margins and tips can scorch) • stunted growth • reduced yield and quality	▪ high pH soils ▪ after heavy liming ▪ soils with high levels of metallic ions ▪ poorly drained and/or aerated soils ▪ soils with high levels of copper ▪ soils with low potassium levels especially when associated with high potassium levels	Vines, fruit crops, stone fruits, citrus, vegetables, field peas, beans and cereals
Manganese (Mn)	▪ essential for chlorophyll production and photosynthesis. ▪ aids nitrogen and carbohydrate metabolism ▪ oxidation reduction ▪ involved in the activity of several enzymes ▪ combines with copper, iron and zinc to aid plant growth processes.	• chlorosis of recently matured leaves with no reduction in leaf size • less pronounced mottling in some broad leaf plants • small grains can show a longitudinal striping • “grey fleck” in oats • chlorosis in citrus (more evident on the shady side of the tree	▪ high pH soils ▪ limed soils ▪ light sandy soils ▪ soils low in potassium ▪ soils low in organic matter ▪ soil high in copper, iron and zinc ▪ cold wet periods ▪ soils that have evolved from parent materials low in manganese	Citrus, pome fruit, stone fruit, vines, strawberries, tomatoes, potatoes, legumes, vegetables, cereals (especially oats), sorgham

NUTRIENT	FUNCTIONS IN THE PLANT	DEFICIENCY SYMPTOMS	CONDITIONS THAT REDUCE AVAILABILTY	SENSITIVE CROPS
Molybdenum (Mo)	▪ is a co-factor in the enzyme nitrate-reductose ▪ aids in the conversion of nitrates of ammonium (the initial stage of synthesis of proteins) ▪ essential for Rhyzobia to enable legume crops to fix aerobic (atmospheric) nitrogen ▪ helps plants to utilise nitrate nitrogen ▪ involved in phosphate and iron metabolism	• in general similar to nitrogen deficiency - yellowing or pale leaves, stunting, necrotic leaf margins and tips (this is because without molybdenum plants cannot metabolise nitrogen) – symptoms start in older leaves first • flowers can wither or be suppressed	▪ low pH soils – particularly if they contain aluminium and/or iron oxides ▪ soils with high copper levels ▪ soils with low phosphate levels ▪ soils derived from parent materials low in molybdenum	Cucurbits (cucumbers, melons etc.) Crucifers (cabbage, canola, cauliflower etc.) Legumes (beans, lucerne, peas, soya beans etc.)
Zinc (Zn)	▪ necessary for the formation of chlorophyll ▪ involved in several enzyme systems, the growth hormone auxins and the synthesis of nucleic acids ▪ plays a part in the intake and use of water in by plants.	• stunted growth • leaves reduced in size and misshapen • chlorosis (leaf mottling) leading to necrosis and premature leaf fall • chlorotic leaves and dieback in citrus • rosetting and/or “little leaf” in fruit trees • “tram lining” – light striping both sides of the midrib- in maize • bronze spotting on older leaves later giving a mottled appearance in legumes • reduced development and size of fruit	▪ soils evolved from parent material low in zinc ▪ high pH soils and soils heavily limed ▪ clay soils with high magnesium levels ▪ soils high in organic matter ▪ soils high in potassium ▪ soils that have been leveled, exposing the sub-soils ▪ soils that have had high nitrogen inputs ▪ cold wet conditions (availability can often be delayed at spring time)	Cereals, cotton, fruit, pip and citrus trees, nuts, oilseed crops, pome fruit, rice, stone fruit, vegetables.

POSSIBLE EFFECTS OF pH AND SOIL TYPE ON NUTRIENT AVAILABILITY

	Low pH <6.0	Normal pH 6.0 – 7.0	High pH >7.0
Sandy soils	Nitrogen Phosphorus Potassium Magnesium Sulfur Boron Copper Molybdenum Zinc	Nitrogen Potassium Magnesium Sulfur Boron Copper Manganese Zinc	Nitrogen Phosphorus Potassium Magnesium Sulfur Boron Copper Iron Manganese Zinc
Sandy Loam	Nitrogen Phosphorus Potassium Magnesium Copper Molybdenum	Nitrogen Magnesium Sulfur Boron Copper Manganese Zinc	Nitrogen Phosphorus Magnesium Sulfur Boron Copper Iron Manganese Zinc
Loam	Phosphorus Potassium Molybdenum	Boron Manganese	Boron Copper Iron Manganese Zinc
Clay Loam	Phosphorus Potassium Molybdenum	Manganese	Boron Manganese Zinc
Clay	Phosphorus Molybdenum		Boron Manganese Zinc
Organic soils – Peat	Phosphorus Copper Zinc	Copper Manganese Zinc	Boron Copper Manganese Zinc
Thin soil over Limestone	Magnesium	Magnesium Copper Manganese Zinc	Magnesium Copper Manganese Zinc

NUTRIENT MOBILITY

Nutrient mobility in soil

Very Mobile – (prone to leaching)

nitrate Nitrogen, sulfate Sulfur, Boron

Moderately Mobile –

ammonium Nitrogen (ammonium Nitrogen is temporarily immobile), Potassium, Calcium, Magnesium, Molybdenum

Immobile –

organic Nitrogen, Phosphorus, Copper, Iron, Manganese, Zinc

(Chelated forms of Copper, Iron, Manganese and Zinc are mobile and resistant to leaching)

Nutrient mobility in plants

Very mobile –

Nitrogen, Phosphorus, Potassium, Magnesium

(Deficiency symptoms appear first in older leaves and quickly spread throughout the plant)

Moderately mobile –

Sulfur, Copper, Iron, Manganese, Molybdenum, Zinc

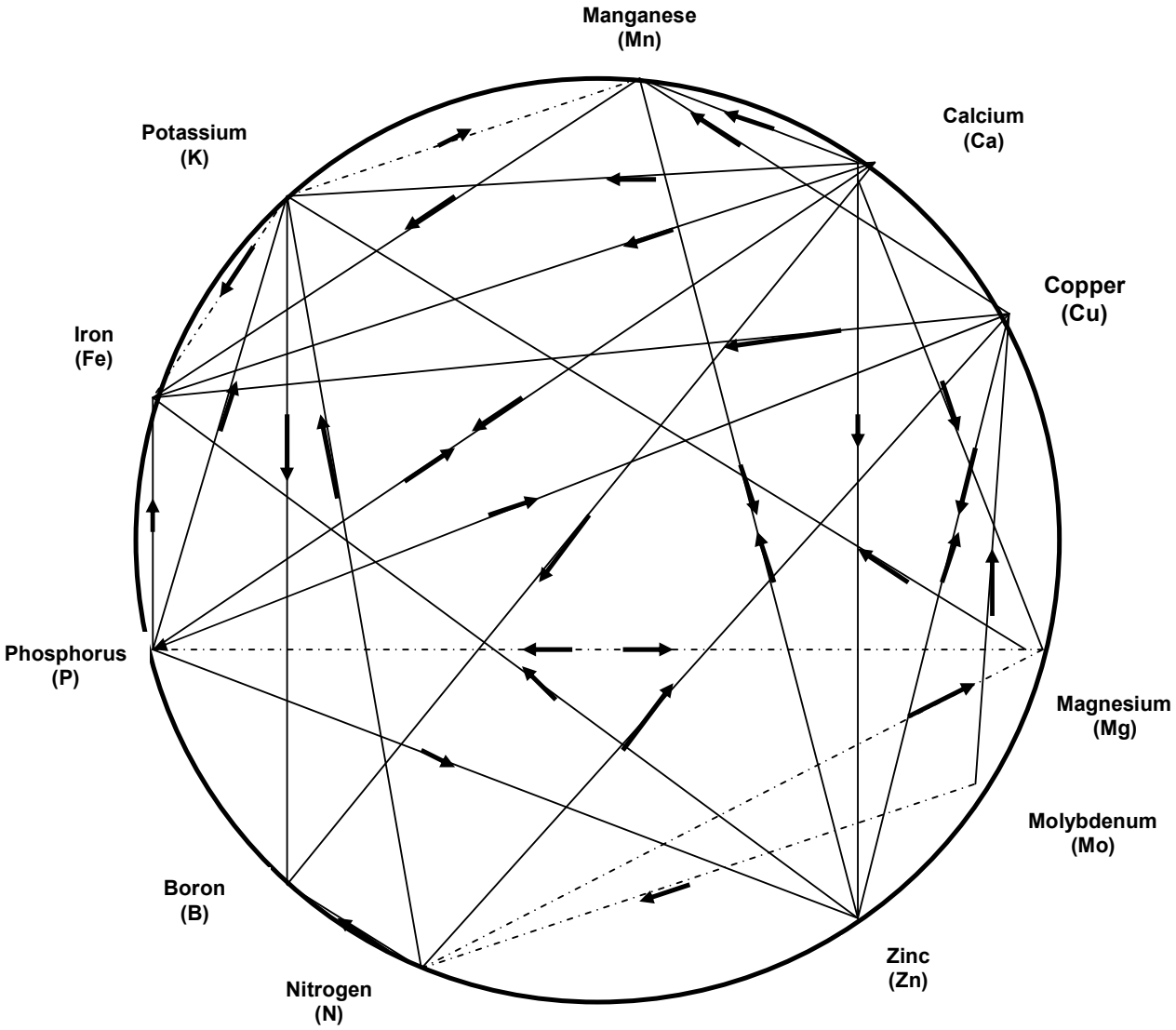
(Deficiency symptoms first appear in new growth but do not readily translocate to old growth)

Immobile –

Boron, Calcium

(Calcium is very immobile)

SOIL ANTAGONISM AND INTERACTION CHART



Interaction

Antagonism

NUTRIENT ANTAGONISM AND INTERACTION

NITROGEN

When high levels of Nitrogen induce accelerated growth rates, levels of micronutrients that would normally be marginal can become deficient.
High soil levels of Nitrogen can assist Phosphorus, Calcium, Boron, Iron and Zinc but an excess can dilute these elements.
Low soil levels can reduce Phosphorus, Calcium, Boron, Iron and Zinc uptake.
Ammonium Nitrogen can make Molybdenum deficiency appear less obvious.

PHOSPHORUS

High levels of Phosphorus reduce Zinc and, to a lesser degree, Calcium uptake. It is antagonistic to Boron in low pH soils.

POTASSIUM

High levels of Potassium reduce Magnesium and to lesser extent Calcium, Iron, Copper, Manganese and Zinc uptake. Boron levels can either be low or toxic.
Low levels can accentuate Iron deficiency.

CALCIUM

High levels of Calcium can accentuate Boron deficiency. Liming can decrease the uptake of Boron, Copper, Iron, Manganese and Zinc by raising soil pH.

COPPER

High levels of Copper can accentuate Molybdenum and to a lesser degree Iron, Manganese and Zinc deficiency.

IRON

Iron deficiency can be accentuated by limimg, low Potassium levels or high levels of Copper, Manganese or Zinc.

MANGANESE

High levels of Copper, Iron or Zinc can accentuate Manganese deficiency – especially repeated soil applications of Iron. Uptake can be decreased by liming or increased by Sulfur applications (because of the affects on pH)

MOLYBDENUM

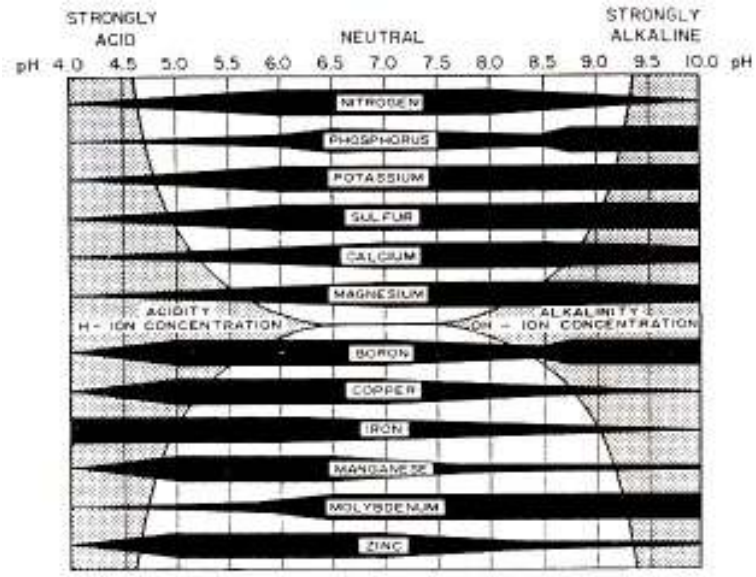
Deficiencies can be accentuated by high levels of Copper and to a lesser degree Mnaganese. Uptake can be adversely affected by sulfates. Uptake can be increased by phosphates and liming.
Molybdenum can increase Copper deficiencies in animals.

ZINC

Uptake can be decreased by high Phosphorus levels, liming or high levels of Copper, Iron or Manganese. Zinc deficiencies are often associated with Manganese deficiencies, especially in citrus.

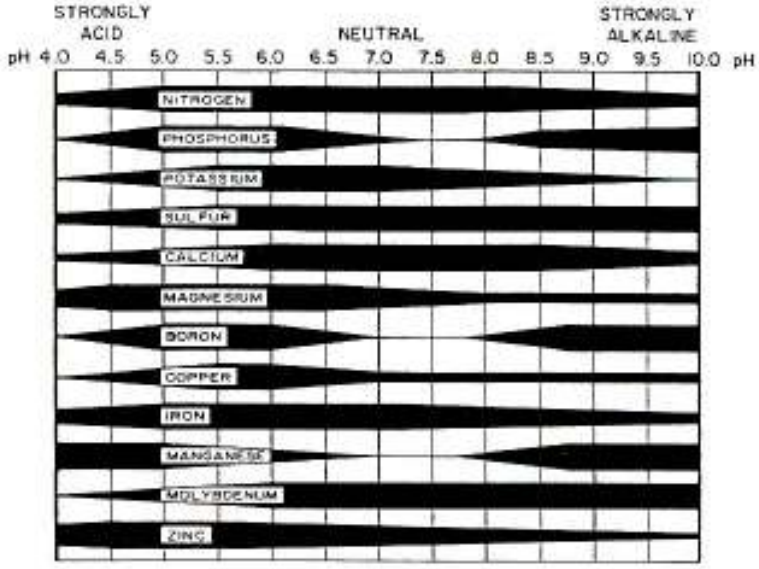
EFFECT OF SOIL REACTION ON AVAILABILITY OF NUTRIENTS

The availability of nutrients at specific pH ranges differs between mineral and organic soils. The following charts demonstrate these differences.



Influence of pH on the availability of plant nutrients in mineral soils; wildest parts of the shaded areas indicate maximum availability of each element

Adapted from L.B.Nelson (Ed.) *Changing Patterns in Fertiliser Use,* Soil Science Society America, Madison,WI (1968).



Influence of pH on the availability of plant nutrients in organic soils; widest parts of the shaded areas indicate maximum availability of each element.

Adapted from E.E. Lucas and J.F. Davis. Relationships between pH values of organic soils and availability of 12 plant nutrients, *Soil Science* 92:177-182 (1961)