Hydroponics	Julius Von Sachs Growing plants in nutrient solution (soil-free)
Macronutrients	Present in excess of 10 mmole/kg of dry wt. C, H, O, N, P, K, S, Ca, Mg N requirement is the greatest
Micronutrients	Less than 10 mmole/kg of dry wt. Fe, Mn, Cu, Mo, Zn, B, Cl, Ni Fe is required the most

Elements that activate enzymes	Mg^{2+} - RuBisCO and PEP carboxylase Zn^{2+} - Alcohol dehydrogenase, carboxylase Mo - Nitrogenase, nitrate reductase Fe^{3+} - Catalase
Potassium	Present in abundant quantities in meristematic tissues, buds, leaves and root tips Plays role in opening and closing of stomata, protein synthesis, ionic balance, enzyme activation and turgidity
Calcium	Calcium pectate in the middle lamella of cell wall Mitotic spindle formation Gets accumulated in older leaves and not remobilised

Sulphur	Amino acids- cysteine and methionine Thiamine, biotin, coenzyme-A, ferredoxin
Iron	Absorbed as Fe^{3+} Electron transport proteins- ferredoxin, cytochromes Formation of chlorophyll
Manganese	Absorbed as Mg^{2+} Splitting of water during photosynthesis

Zinc	Absorbed as Zn^{2+} Synthesis of auxin Activation of carboxylases, alcohol dehydrogenase
Boron	Absorbed as BO_3^{3-} and $B_4O_7^{2-}$ Required for Ca^{2+} uptake and utilisation Pollen germination, cell elongation and differentiation Carbohydrate translocation
Molybdenum	Absorbed as MoO_2^{2+} Plays role in nitrogen metabolism

Chlorine	Absorbed as Cl^- Required for ionic balance and splitting of water to liberate oxygen during photosynthesis
Actively mobile elements	Na, K, Mg Deficiency symptoms first in older tissues
Immobile elements	Ca, S Deficiency symptoms first in younger tissues

Chlorosis	Loss of chlorophyll and yellowing of leaves Due to deficiency of N, K, Mg, S, Fe, Mn, Zn and Mo
Necrosis	Death of tissue Due to deficiency of Ca, Mg, Cu, K
Inhibition of cell division	Due to deficiency of N, K, S

Delay in flowering	Due to deficiency of N, S, Mo
Manganese toxicity	Chlorotic veins surrounded by brown spots Induces deficiency of Fe, Mg and Ca
Nitrification	Ammonia to nitrite (NO_2^-) by *Nitromonas, Nitococcus* Nitrite to nitrate (NO_3^-) by *Nitrobacter*

Denitrification	Nitrate is reduced to nitrogen by *Pseudomonas, Thiobacillus*
Biological nitrogen fixation	Atmospheric nitrogen is converted to ammonia by nitrogenase enzymes
Free-living nitrogen fixers	Aerobic- *Azotobacter and Beijernickia* Anaerobic- *Rhodospirillum* Cyanobacteria- *Anabaena, Nostoc*

Symbiotic nitrogen fixers	*Rhizobium*- in the root nodules of legumes, e.g. alfalfa, beans, peas, lentils, clover *Frankia*- non-leguminous pleats, e.g. *Alnus, Casuarina*
Root nodule formation	Initiation in the cortex of the root Requires 8 ATP molecules per molecule of ammonia produced Energy is derived from respiration of host cells
Nitrogenase	Present in root nodules Mo-Fe protein, oxygen sensitive enzyme Converts atmospheric nitrogen to ammonia

Leghaemoglobin	Gives distinct pink colour to root nodules Acts as a scavenger of oxygen and reduces free oxygen in root nodules for nitrogenase activity Maintains high oxygen concentration bound to it for aerobic respiration
Utilisation of ammonia	Amination- Formation of glutamic acid from α-ketoglutarate. Enzyme involved is glutamate dehydrogenase Transamination- Formation of other amino acids from glutamic acid
Transportation of nitrogen	Mostly as amides- asparagine and glutamine through xylem As ureides in soybean