PCP 508: PLANT NUTRIRTION AND WATER RELATIONS

Plant nutrition is a sub science of Plant Physiology. It addresses issues on elements plant needs to absorb, to grow and to live, deficiency symptoms and how to address deficiency symptoms problems in a plant. Plant nutrition also deals with the functions of nutrient elements in plants.

SCOPE OF MINERAL NUTRITION

Plant mineral nutrition has two (2) major aspects:

i) Acquisition of mineral nutrient.

ii) Functions of those minerals in the plant.

i. Acquisition of Mineral Nutrients

All living things consist of atoms of bio-chemical elements. The ultimate reservoirs of these elements on earth are the rocks, oceans and the atmosphere. Rocks are weathered into soil. Oceans and the water that is released into lakes, streams and soils as well as the atmosphere itself make up the compounds, aggregates, solution and gases which living organisms mine/ exploit for the elements, which plants absorb to form their bodies. Only green plants and certain microorganisms are capable of extracting simple ions and inorganic compounds from the environment without having to rely on complex energy rich compounds previously synthesized by other living organisms. These organisms are autotrophic. The photosynthetic plants, algae in oceans, streams and lakes and the green plants on land are by far the most important agents in the primary acquisition of elements from the external environment. Once these elements are acquired, they are translocated.

ii. Functions of Nutrients

If one of the elements essential to the plant is present in the environment in insufficient amount/unavailable forms or in difficultly available forms, the deficiencies of these elements in the cells of plant will bring about derangement or destruction in metabolism e.g. P- fruiting, rooting, flowering, N – Vegetative growth (yellowing). These metabolic disturbances will manifest in visible symptoms such as stunted growth, yellowish/purpling of leaves and other abnormalities. These symptoms of deficiency are characteristic for a given element. However, they depend also on the severity of deficiency, the particular specie of plant and many other environmental factors and state of the plant (healthy or not). All these reasons put together will make us focus attention on the functional role of elements in the metabolism of plants. The elements also constitute structural components of compounds and metabolites in the plant.

Translocation

Cells of most algae and other aquatic plants are also exposed to the aqueous medium in which they flow. They take up water and solute from it (H_2O). Terrestrial green plants have tissues that are far removed from the soil, which is the source of water and organic nutrient. In these land plants, there are elaborate structures and mechanisms, which effect a long distance translocation of water and solute within the plant bodies.

Heredity and Environment

All physiological performances of plants including the nutritional characteristics are a function of their genetic constitution and their environment. The great diversity of soil which is the main mineral medium of mineral nutrient constitute a neutral inter-place between heredity and environment in which they live. Plants are adapted genetically and physically for this soil diversity. This aspect is stressed in the ecological aspect of plant nutrition.

Three important aspects of Plant Mineral Nutrition

i. Materials and conditions that must be provided by the environment if plants are to grow normally.
ii. Movement into and distribution of the elements through the plants.
iii. Involvement of the organs of the plants in their metabolism for growth and structure.

HISTORICAL PERSPECTIVE OF PLANT NUTRITION

Early theories on how plants derive their raw materials and how these raw materials were converted within the plants to provide increase in growth, weight and size were philosophical (speculatory) in the absence of the knowledge of chemistry and experimental techniques. The advancement of science was hindered because of this situation, paricularly by the general acceptance of a speculative scheme that was advanced by the Greek national philosopher called Aristotle (384-322 B.C). He held the view that all matter consisted of four elements:

i) Earth
ii) Water
iii) Air
iv) Fire

He was a tutor of Alexander the Great.

Rationalization of Aristotle

i) Plants have no digestive tract for modifying food from the environment.
ii) Plants obtained from the soil food that was preformed (already established or made suitable for plant growth and development).
iii) Plants play passive role in nutrition.

Aristotle's opinion held sway for over 2000 years until the beginning of modern science in the 16^{th} century. Theophrastus (371 – 285**)** the father of Botany. He studied under Aristotle and Platum. He made remarkable observations on plants especially in areas of ecology and physiology. However, his efforts were not related to Plant nutrition.

Two (2) schools of thought predominated:

i) Water theory
ii) Humus theory

Water Theory
Water theory stated that plants derive most if not all of their substances from water.

Humus Theory
It stated that plants feed only on decaying animals or vegetative matter.

The advantage of water theory is that plants in aqueous solution absorb the inorganic nutrients from aqueous solution.

The advantage of humus theory is that saprophytic plants depend entirely on decaying animals and vegetative matter. However, this is not true for all photosynthetic plants.

A. **Nicholas de Cusa** (1450BC) recognized that plants take up ash constituents in small amount from the soil and these are conveyed in the water, which forms the bulk of the plant.

B. **Job van Helmont** (1577-1644BC) was a Belgian physician. He was honoured as being the first man to conduct qualitative experiment in plant nutrition. He investigated the source of materials that plants are composed of.
Hypothesis: That all vegetable matter immediately and materially arise from elements of water alone.

i) He took a pot
ii) He put 200 pounds (lbs) of oven-dried soil.
iii) He soaked the soil with water
iv) He planted a willow shoot of 5lbs.

After five years, the willow shoot had grown to about 169lbs 3oz. the pot was constantly irrigated daily with rain or distilled water. He covered the soil to prevent dirt from entering. After five years, he dried the soil and found that the weight was still 200lbs but short of 2oz. so he concluded that, the 164 lbs of wood had arisen from the water alone.

Importance/Appraisal

i) This was one of the first controlled experiments.
i) It was a well planned, carefully executed and accurately described.
ii) It was the first qualitative attempt to gain insight into the origin of increase in fresh weight of a plant.

However, He overlooked the importance of atmosphere in plant growth. The 2oz difference in the weight of the soil was overlooked.

C. **John Woodward** (1656-1728BC) his work demonstrates the importance of mineral matter to plant growth. His experiment was the earliest recorded experiment. He grew plant in water from four different sources;
- Rain water
– Water from river Thames
– Water from Hyde Park conduit
– Water from Hyde Park and mould.

Result:

Water source	Weight of plant	Weight of plant after exp.	Mean of weight**
Rain water	285	45.75	17.5
Water from river Thames	28	54	26
Water from Hyde Park	110	249	139
Water from Hyde Park and mould	92	376	284

Appraisal

All the plants had adequate water, therefore all the plants could have made equal growth had nothing been added. However, the amount of growth increased with the impurity of water. He concluded that vegetables are not formed from water alone but from certain peculiar terrestrial matter. A great part of terrestrial matter mixed with the water passes on into the plant along with water. He therefore concluded that the earth (soil) and not water constitutes vegetable.

D. STEVEN HALES: This is the father of plant physiology. The highest award by the American Association of Physiology. He was interested in sap of plants and he made measurement of the amount of water absorbed and transpired by plants. He related this amount to the area of the root surface through which the water was absorbed and area of leave surfaces through which it was transpired and calculate relative velocity of water movement through a unit of root surface and unit area of leaf surface. He wrote a book titled 'The Vegetable Statics' in 1727. The book describes several experiments in plant physiology. He had a passion for exact measurement.

E. Ingen Housz (1730 – 1799): He discovered that light was essential for evolution of oxygen for green plants. He also observed that green plants give carbohydrate in the darkness and non-green plants give out both carbohydrate and oxygen in the darkness. His work also shows that leaves are the primary organs of food production and carbon from carbohydrate is the primary source of carbon for plants inspite of its low concentration in the air.

F. Jean Senebier (1742 – 1809): He demonstrated that only the green portion of leaves were photosynthetically active. He repeated several experiments of Ingen Housz. He was the first investigator to give a reasonable insight into photosynthesis. He found out that the amount of O_2 given out by green plants kept in water was proportional to the concentration of CO_2 dissolved in water. He also showed that it was light and not the heat from the sun, which induces giving off O_2. He also published a book called 'Physiologia Vegetale, 1800.'

DRY MATTER

When fresh plant materials are dried at 70°C for 24-48hrs, the dry matter remaining will be roughly 10-20% of the initial fresh weight. The results of chemical analysis of plant tissues are always expressed based on their dry matter rather than on their fresh weight. Fresh weight is a variable changing with time of the day, amount of water in the soil, soil temperature, wind velocity and other factors. Over 90% of dry weights of most dry matter contain carbon, hydrogen and oxygen e.g. in maize, C is about 43.5%. O is 44.3% and H is 6.2%. The bulk of the dry weight of plant is due to the cell walls, which consist mainly of cellulose and lignin. Surrounded by the cell wall is the cytoplasm i.e. the sum total of the protein and other chemical entities (lipids, amino acids, organic acids and other elements) which make up the living machinery of the cell.

Mineral composition

If only 10-20% of fresh weight of a plant is the dry matter and all of these except C, H and O, it follows that all the other elements (except C, H and O) together account for only 1.5% of the fresh weight of plants. To determine the mineral element content of the plant, the investigator ashes the dry plant material thereby removing the organic C compound and then analyzing the ash for the element for which he is interested.

Percent Elemental composition of the stem, leaves, cob and grain of maize plant

Element	% of dry matter
Carbon	43.6
Oxygen	44.4
Hydrogen	6.2
Nitrogen	1.5
Sulfur	0.16
Phosphorus	0.20
Calcium	0.22
Potassium	0.921
Magnesium	0.179
Iron	0.083
Manganese	0.035
Silicon	1.172
Aluminum	0.107
Chorine	0.143
Undetermined	0.933

ESSENTIAL AND OTHER MINERAL ELEMENTS

The presence of an element in a plant does not in itself signify that the element plays an essential role in the life of that plant. The soil contains numerous chemical elements. With sufficiently sensitive methods, a majority of the elements in the periodic table could be detected in any soil sample. Thus, a plant grown on such soil when analyzed would be found to contain at least traces of most of the elements those essential for its growth as well as others taken up because the absorption mechanism does not make absolute selection between essential and other elements.

Criteria for essential

Arnon and Stout, 1937 and Epstein, 1965, developed the four (4) criteria.

i) Deficiency of the element makes it impossible for the plant to complete the vegetative and reproductive phases of its life cycle (i.e. form viable seeds) e.g. N for vegetative growth

ii) The deficiency symptoms must be specific for the element in question and must be prevented and corrected by only supplying that element i.e. it cannot be replaced by any other element e.g. P for flowering, rooting and fruiting.

iii) The element must be directly involved in metabolism or it must be part of the molecule of an essential plant constituent e.g. Mg – Chlorophyll, N in proteins

iv) The deficiency symptoms described for the element must be observed in a representative number of plant families N deficiency in several plant families

Macronutrients/major elements

At present, there are seven mineral elements referred to as macro elements N, P, K, C, Mg, S and Fe. The elements are referred to as macronutrients because they are required in large quantities $\geq$ 1000 mg/g dry matter.

Micro/minor/trace nutrients

In addition to Fe, six other elements have been identified to be taken up by plants in relatively small amounts and they have been found to be essential. They are Mn, Cu, Zn, Bo, Mo and Cl. They are needed in quantities $\leq$ 100 µg/g dry matter.
Mn is essential for oat, soybeans, tomatoes and cowpea.
Zn is essential for barley, sunflower and several types of beans.
Mo is essential for N-fixing bacteria.

Elements Essential for Specific Plants under Specific Conditions

Co: General requirement for higher green plants has not been established, however, Co has been found to be essential for blue-green algae. It is also essential for legumes relying on N fixation as source of N. Therefore, Co is an indirectly essential element in N-fixation by microorganism in root nodules on legumes and many non legumes.

Vanadium (Vd): it was found to be essential for green algae and no higher green plants has shown requirement for Vanadium.

Na: It has been shown to be essential for blue-green algae and angiosperms. Sugar beet needs Na.

Si: Plant grown in Si rich soil invariably contain appreciable amount of Si. But experiments with plants grown in nutrient solution in which Si was omitted have generally failed to show that Si is important. Rice fails to grow normally in solutions lacking Si but its essentiality has not been shown for rice.

I: It has been shown to be essential for marine red algae.
Some elements can partially substitute for essential elements e.g. Rb = K, Sr = Ca in some algae and bacteria. Va = Mo in some nitrogen fixing microorganisms. Na = K in sugar beet.

Concerning essentiality of elements, it is incorrect to make an absolute statement that an element is not essential for plant growth. It is better to say that such an element is not proven essential.

Essential elements for most higher plants

Element	Chemical symbol	Available form
Molybdenum	Mo	$MoO_4^{=}$
Copper	Cu	Cu^{+}, Cu^{2+}
Zinc	Zn	Zn^{+2}
Manganese	Mn	Mn^{+2}
Boron	B	$H_3BO^-_3$
Iron	Fe	Fe^{+3}; Fe^{+2}
Chlorine	Cl	Cl^-
Sulfur	S	$SO_4^{=2}$
Phosphorus	P	$H2PO_4^-$; $HPO_4^{=}$
Magnesium	Mg	Mg^{+2}
Calcium	Ca	CA^{+2}
Potassium	K	K^+
Nitrogen	N	$NO^-_{3;}$ NH_4^+
Oxygen	O	$O_{2:}$ H_2O
Carbon	C	CO_2
Hydrogen	H	H_2O

HYDROPONICS

Hydroponic cultute is growing plants by immersing their roots in an aqueous nutrient solution with known concentration of nutrients.

Disadvantages

i. Need for aeration
ii. Frequent replacement of solution every day or two for maximum growth because certain ions are absorbed more rapidly than others thus resulting in change in pH

Many plants grow well in solutions having concentrations of essential nutrients as low as those dissolved in the soil solution, provided the solutions are replenished enough to maintain such solutions.

Growth as a function of the concentration of any element in plant tissue

When the concentration of a nutrient is in the **deficient zone** and the element is provided such that its concentration is increased in the plant, the growth rate is stimulated dramatically. After the **critical concentration** (minimal tissue concentration giving almost maximal growth), increases in concentration (fertilization) do not appreciably affect the growth rate (**adequate zone**). The adequate zone represents luxury consumption of the element. The zone is fairly wide for most elements but narrow for micro nutrients. Continued increases of these elements usually lead to toxicities and a reduced growth rate (toxic zone)

ROLES AND FUNCTIONS OF MINERAL ELEMENTS

a) Constituents of metabolites or complexes
b) Activators, cofactors, or regulators of enzymes.
c) Elements involved in physiological processes.

A. Constituents of metabolites

1. **Nitrogen:** N is the abundant after C, H and O. Protein contains about 16-18% N. N is normally absorbed as Nitrate NO^{3-} and it is reduced and incorporated into organic compounds. N is a constituent of amino acids, nucleotides and co-enzymes. About 70% of the total leaf N is found in the chloroplast. N is also found in peptide bonds, nicotine, morphine, caffeine.

2. **Phosphorus:** Is largely absorbed as H^2PO^{4-}, $HPO^{4=}$ and as phosphate PO_4^{3-}. P is one of the three (3) elements that are absorbed as complex anions; the other two are nitrate and sulphate. Unlike N and S in NO^{3-} and SO_4^{2-}, the P atom of the biphosphate is not reduced in the cell to any lower oxidation state. PO_4^{3-} plays a key role in element metabolism incorporated into ATP. It is part of the universal element currency of all living cells of whatever specie. PO_4^{3-} occurs in phospholipids including those of membranes. It also occurs in sugar phosphate in various nucleotides as co-enzymes. In seeds, PO_4^{3-} is stored as phytic acid or as phytin.

3. **Sulphur:** It is absorbed mainly in the form of SO_4^{2-} ion. It is incorporated into organic compounds. It is a constituent of Sulphur containing amino acids (methionine, cystine and cysteine). Therefore, S is a constituent of protein containing these amino acids. Vitamins and co-enzymes also contain S. the pyridoxines which are non-heme proteins involved in photosynthesis and other element transfer processes contain S. volatile compounds containing S contribute to the characteristic odour given off by onions, mustard and other plants.

4. **Magnesium:** Chlorophyll is the major stable compounds of plants, which contain an atom of Mg as a fixed constituent (constant). The compounds bearing this chlorophyll molecule is Mg-porphyrins**.** Mg represents 2.75% of molecular weight of chlorophyll. Since half or more leaf Mg may be present in the chloroplast, these plastids therefore contain more Mg in addition to that which is part of chlorophyll. Element conversion and conservation are the major functions of the chloroplast. In addition to its role in the chlorophyll, Mg is the most common activator of enzymes that are involved in element metabolism.

5. **Iron:** There are many metabolites containing atoms of Fe as fixed constituents of their molecules. Fe is an integral part of protein. It is part of the Fe-porphyrins called *heme*. They function prominently in element transfer. The role of heamoglobin in symbiotic N fixation is not well-understood i.e. very complex process. The other Fe-porphyrin enzymes include peredoxases and dehyrogenases. They are non-heme Fe proteins.

6. **Manganese:** It is a constituent of many enzymes but only one enzyme has been isolated called mangaloprotein (manganin).

7. **Zinc:** It is a metal component of a number of metallo-enzymes. These enzymes include alcoholdehydrogenase and lactic dehydrogenase.

8. **Copper:** It is a component of different enzymes including ascorbic acid oxidase, phenolases and others. It is also a constituent of cytochrome auxins.

9. **Calcium: I**t is a metal component of metallo-enzymes called amylase in animal tissues and microbial tissues. Ca is commonly the major cation of the middle lamella of cell wall.

10. **Molybdenum (Mo):** It is the metal of several enzymes involved in N fixation and N reduction.

11. **Cobalt:** It is a constituent of Vit. B_{12} (Cyano-cobalamine enzyme). All N fixing systems require Co.

12. **Potassium, Chlorine and Boron:** No enzyme has been isolated containing these elements.

B. Nutrients as co-factors, activators or regulator of enzymes

1. **Nitrogen:** Certain enzyme activities cannot be demonstrated if the organism has been grown in the absence of the substrate of such enzymes, but their activities become apparent when the organism is exposed to the substrate. Factors other than the substrate may also be instrumental in inducing the enzyme. NO^{3-} reductase enzyme (NR) is such an inducible enzyme in plants being induced by NO^{3-} ion. This process of induction represents enzyme synthesis. NH^{4+} activates some enzymes for which K^+ is the main activator.

2. **Phosphorus:** P regulates many enzymic processes. Phosphorylation of ADP to ATP and its dependence on the concentration of PO_4^{3-} is important and is dependent on the presence of the PO_4^{3-}.

3. **Magnesium:** Is an activator of more enzymes than any other elements. It is a co-factor of nearly all enzymes acting on phosphorylated substrate. It is therefore of great importance in energy metabolism. Activation by Mg is not highly specific, Mn can frequently substitute for Mg. Mg also activates some enzymes not concerned with PO_4^{3-} transfer.

4. **Manganese:** Mn is often substituted for Mg as an activator of PO_4^{3-} transferring enzymes e.g. Agenase. Mn is prominent as an activator of enzymes involved in reactions of Krebs cycle.

5. **Molybdenum:** Functions mainly as a component of metalloenzymes rather than activator of enzymes. It plays a major role in the induction of nitrate reductase (NR).

6. **Chlorine:** Acts in conjunction with other enzymes in photosystem II (photolysis of water).

7. **Boron:** Plays a regulatory role in carbohydrate metabolism.

8. **Potassium:** It is the only monovalent cation essential for higher plants. It is an activator of numerous enzymes.

C. Roles of nutrients in physiological processes

Numerous processes are governed by nutrient elements as substrates' component of metabolites, activators and inhibitors; they affect the rate of many enzymes catalyzed reactions. Highly integrated sequences of enzyme-catalyzed reactions are recognized as metabolic or physiological processes. The common method of investigating physiological functions of a given nutrient is to study the biochemical effects of its deficiency. When an essential element is efficient, growth is inhibited. When the element is re-supplied, there are two (2) obvious consequences:

i) The content of that element in the plant will increase because of renewed absorption of it.
ii) Growth will resume if no other factor is inhibitory.

1. **Nitrogen:** An early dramatic symptom of N deficiency is a general yellowing of leaves – chlorosis due to an inhibition of chlorophyll synthesis. The internal appearance of the plastids is altered considerably. The resulting slow down of photosynthesis causing an N deficient plant to lack not only essential amino acids and also the machinery for the synthesis of necessary carbohydrate and Carbon skeleton for all manner of organic synthesis. Before chlorosis sets in, carbohydrate including starch may accumulate since they are not utilized for protein synthesis because of the deficiency in amino acids. Plant absorb N in NO_3^- or NH_4^+. Absorption of NH_4^+ results in the reduction of the P^H of the medium, whereas the absorption of $NO3^-$ has the opposite effect. In most well aerated soils, NO_3^- is the principal form of available N. some plants can also utilize ammonium N. low P^H reduces availability of some microelements e.g. Cu, Mn, Fe. The structure of the chloroplast is affected under the condition of NH_4^+ toxicity.

2. **Phosphorus:** Plays a major role in element metabolism i.e. it is necessary for ATP synthesis and phosphorilated compounds. The deficiency of P causes immediate and severe disruptions of metabolism and development. P promotes the absorption of Molybdate by plants. The chloroplast of P deficient plants show various abnormalities but the obvious and most common deficiency of P is purple colouration of leaves.

3. **Sulphur:** The consequences of S deficiency are low level of carbohydrate and build up of soluble N fractions including nitrate. In S deficiency, there are fewer cytoplasmic inclusions and their appearance are abnormal.

4. **Magnesium:** As a constituent of chlorophyll and as an activator of numerous enzymes, its deficiency affects every facets of metabolism in plants. Chlorosis is an early symptom followed by diminished photosynthesis. In Mg deficient plant, the fine structure of the chloroplast becomes abnormal.

5. **Iron:** It is essential for chlorophyll synthesis. The appearance of chloroplast is changed if Fe is deficient i.e. the no and the size of grana are much reduced. Element relation is also disrupted when Fe is deficient because Fe contains element carriers.

6. **Manganese:** It is also a prominent component of chloroplast because it is involved in photolysis of water (light reaction) and it participates in the reaction leading to the evolution (giving up) of $O_{2.}$

7. **Zinc:** Zn deficiency is termed 'little leaf' or resetting. Rosetting is the failure of internodes to elongate causing the leaves of several nodes to lie together in a plane. The masked Zn deficiency on growth results from its influence on the auxin level. The concentration of IAA in Zn deficient tissue drops well before visible symptoms become apparent and upon resupplying Zn, it rises. Protein synthesis, which is mediated by RNA, is regulated by the concentration of Zn.

8. **Copper:** Cu deficiency interferes with protein synthesis and causes an increase in soluble N compound.

9. **Molybdenum:** Mo deficient plants have lower level of sugar and ascorbic acid. Concentrations of most amino acids are usually low in Mo deficient plants.

10. **Chlorine:** Cl is required in the evolution of O^2 by photosystem II in photosynthesis. Cl deficient plants have the tendency to wilt.

11. **Boron:** Growing points of both shoot and root stops elongation when Bo is deficient, and if severe deficiency continues, they become discoloured, disorganized and die.

WATER RELATIONS

Learning Expectations:

1. Functions of water in crop plant
2. Physical and chemical properties of water
3. Concept of water potential and its components
4. Water relationship of whole plant (Soil-Plant-Atmosphere Continuum (SPAC)
5. Factors controlling rate of water uptake
6. Water deficit, water use strategy and crop yield

Functions of water in Crops:

1. Cell Enlargement: The growth process in plant is directly related to the uptake and transportation of water into the cell. Presence of water deficit would greatly compromise growth process
2. Structural support
3. Evaporative cooling
4. Substrate for biochemical process in crops
5. Transport of solutes in the crop plant

Physical and chemical properties of water

1. Bipolarity: The angular arrangement of oxygen and hydrogen in water molecule leads to the emergence of bipolarity. The covalent bond resulting from this bipolarity results in hydrogen bond when two water molecules are found together in a medium. All the properties the physical and chemical properties of water are as a result of this hydrogen bond between water molecules.
2. Liquid at physiological temperature: Because of the strength of this hydrogen bond, water remains a liquid at physiological temperature, despite this comparative smaller molecular weight with respect to other molecules.
3. Incompressibility: As a liquid, water is incompressible, observing all the laws of hydraulics.
4. High Latent heat of Evaporation: The amount of heat needed to transform 1 gram of water into vapour is high, owing to the strong hydrogen bond greater than Van der Waals force. This particular property is very important most especially during transpiration of water vapour leading to evaporative cooling.
5. Cohesion and adhesion: Attraction of similar molecules leads to cohesion. This property was presumed to explain the upward movement of water in the xylem. Adhesion is the attraction of dissimilar molecules between water and other polymers. This wetness property has important property has important implications in water relations.

Concept of water potential

To better describe water quantitatively, it was observed that thermodynamic concepts could be used. In this case the property of water was described with respect to its potential energy, which

is its capability to do work. Pure water was conventionally adopted as the standard water potential, above which it is impossible to obtain higher magnitude of value. The value for pure water is zero. The unit for expressing water potential is Mega Pascal.
The components of water potentials are as follows:

1. Solute potential
2. Turgor pressure potential
3. Matric potential
4. Gravitational potential

Solute water potential is determined by the concentration of the solute present. It decreases with increase in solute concentration, thus its negative value. Turgor pressure potential value could be positive or negative. In a flaccid cell, where there is a net outward movement of water molecule, the value for turgor pressure potential is negative, creating tension; conversely with net inward movement of water into the cell, leading to turgid cell, the value becomes positive or positive hydrostatic pressure. The balance between negative value of solute potential and positive value of Turgor Pressure potential creates a balance, leading to negative water potential, since it is a rarity to have pure water in a cell. Matric Potential is as a result of the adhesion property of water, it is most prominent during the movement of water in the soil. Gravitational potential increases when water is raised above a height above a reference point. Water flows down gravitational potential gradient, all things been equal. At the microscopic level of the plant vascular tissue one may omit the role of gravitational and matric potential components of water potential, though their relevance increases with the increase in organizational level of the plant.

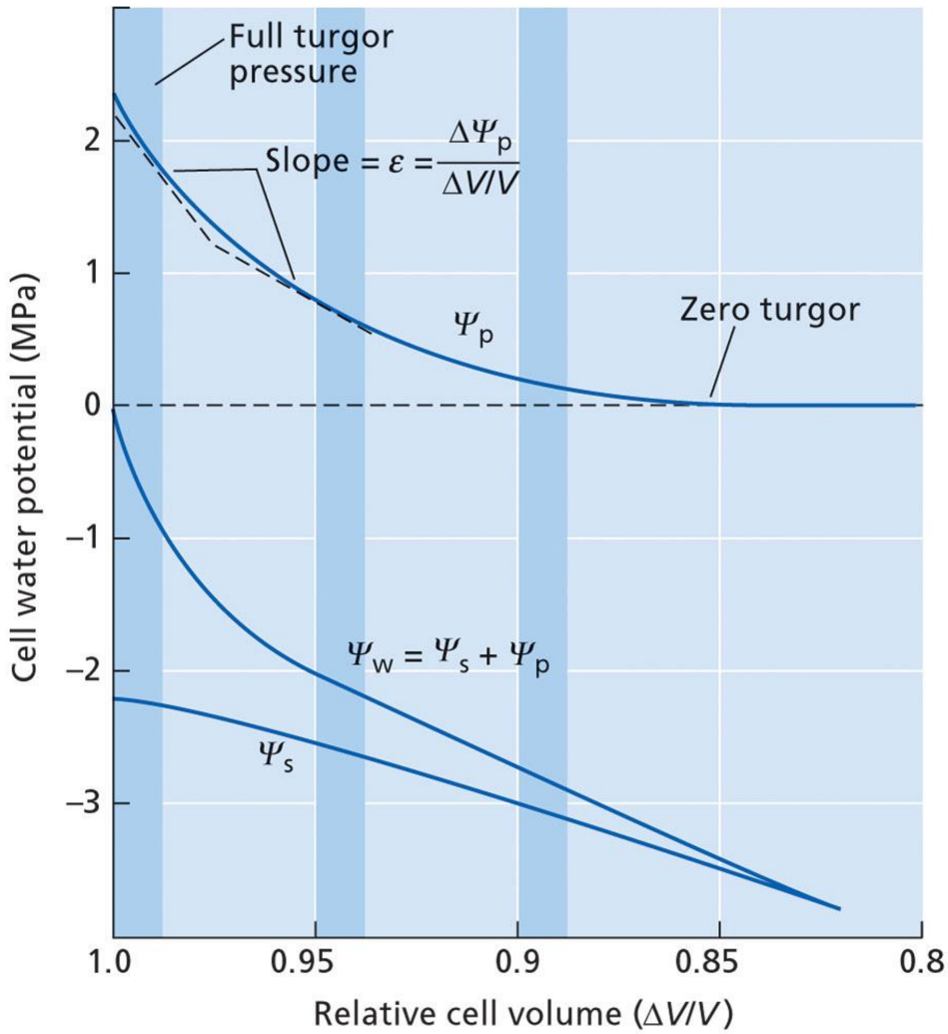
1 Atmosphere = 760mmHg @ Sea level, 45^0 latitude
= 1.013 bar
= 0.1013MPa
= 1.013×10^5 Pa

Water potential components:

$\Phi w = \varphi s + \varphi t + \varphi m + \varphi g$

Where:
Φw – Water potential
Φs – Solute potential
Φt – Turgor potential
Φm – Matrix potential
Φg – Gravitational potential

Interrelationships among the water potential parameters as illustrated in Hofler Diagram



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- Slope of Y_p curve yields the volumetric elastic modulus (e)
  - e is a function of the rigidity of the cell wall
  - High value indicates a rigid wall for which a small vol. change translates into a large drop in Y_p
  - e decreases as Y_p falls b/c walls are rigid only when Y_p is high

This particular diagram shall be discussed in the class with examples.

Tab.1 Driving forces of water in SPAC

Process	Driving forces
Diffusion	Concentration gradient **Fick's Law** $Js = -\Delta s\ \Delta c/\ \Delta x$ Where; Js – Rate of solute diffusion Δs – Diffusion coefficient, measures ease of substance movement via a medium $\Delta c/\Delta x$ – Concentration gradient Δc – Difference in concentration Δx – Difference in distance
Bulk Flow	Pressure gradient $Volume = \pi r^4 \Delta P/\Delta x/8\eta$ Where: Volume - Flow rate r – Radius π – Viscosity of liquid ΔP – Difference in pressure Δx – Difference in distance $\Delta P/\Delta x$ – Pressure gradient

Osmosis	Composite forces (Concentration and pressure gradient)

Tab.2 Water relationship of whole plant (Soil-Plant-Atmosphere Continuum)

Medium/Interface	**Process**	**Driving force**	**Pathway**
Soil	Water movement in the soil/Bulk Flow	Pressure gradient	Soil Particles
Soil-Plant Interface	Water uptake	Composite force $\varphi_w = \varphi_s + \varphi_p$	o Apoplast o Symplast o Trans-membrane
Plant	Long distance transport (Cohesion-tension)	Pressure gradient	Xylem
Plant-Atmosphere	Transpirational pull of water	Gradient of water vapour concentration (Diffusion)	o Stomata o Cuticle o Lenticle

Models of water uptake in plants

Cohesion-tension Model

This model proposes that transpiration of water from the plant leads to the emergence of cohesion among similar water molecules, leading to the build up of negative hydrostatic pressure or tension. The emergence of tension increase tensile strength, which is the ability of water molecule to resist pulling force and by capillary action, water is being pulled up along the xylem. Where gas bubble are trapped in the water column, with an indefinite expansion of this bubble, a collapse of tension in the liquid phase is been observed, thus leading to cavitations. This phenomenon breaks the water column, resulting in reduced water uptake by plant.

Check this URL for animated version of this model:
http://academic.kellogg.edu/herbrandsonc/bio111/animations/0031.swf

Other resources:
http://www.mm.helsinki.fi/mmeko/kurssit/ME325/kuljetusprosessitkertaus.pdf
http://www.uoguelph.ca/plant/courses/pbio-3110/
www.mm.helsinki.fi/mmeko/kurssit/.../kuljetusprosessitkertaus.pdf

Root Pressure Model

An alternative model for the uptake and transportation of water in the plant is the root pressure model. The mechanism is as follows; absorption of solute leads to a reduction of solute potential in the plant cell, by concentration gradient water is being transported along the xylem tissue creating increase in positive hydrostatic pressure or root pressure, thus facilitating water uptake. Excessive uptake of water could lead to guttation, a phenomenon whereby liquid droplets are formed at the edges of the leaf most especially in the morning.

Water deficit, water use strategy and crop yield (This topic is optional, it would have been covered in the previous lectures)

Disequilibrium experienced between water supply and demand creates water deficit in plants. Alternatively, the concept could be envisaged as a situation when water content in the cell/ tissue is less than highest water content exhibited at hydrated state. In fields, drought conditions leads to water deficit accompanied with high temperature. This is a climatic condition.

The response of plant to water stress, which is when water is limiting, is varied and physiological responses are observed at different levels of organisation of the crop. Strategically, plant could avoid or tolerate water deficit. In avoidance, the plant could synchronise his phenology with the growing season in other to optimise the available resources for proper growth and development. With tolerance there must be specific mechanism to ensure availability of water and water use efficiency. Tolerance or resistant strategy involves:

1. Desiccation tolerance at high water potential
    a. Water saver, use water conservatively; example succulent
    b. Water spender, aggressive consumption of water; example Ephemerals
2. Desiccation tolerance at low water potential, possess the ability to function while dehydrated; xeromorphic plants/ non-succulent. There are two strategy for desiccation tolerance at reduced water deficit:
    a. Acclimation, which is transient and phenotypic in nature
    b. Adaptation, which is constitutive and genotypic in nature

Dimension of acclimation are as follows:

I. Osmoregulation – the process of accumulation of solutes in cells independent of cellular volume change. The implication is reduced water potential, osmotic potential and through water uptake increased cellular turgor. The solutes accumulated could be:
    a. Compatible –
        i. Nitrogen containing, e.g. Proline, glycine betaine
        ii. Non-Nitrogen containing, e.g. sugar alcohol (Sorbitol, mannitol)
    b. Non-compatible, e.g. Inorganic ions

II. Reduced growth

III. Phenological variability or phenotypic plasticity (Determinate and indeterminate growth)

IV. Energy dissipation through
    a. Reduced growth of leaf
    b. Changes in leaf orientation (Para and diaheliotropism)
    c. Leaf modification
        i. Wilting
        ii. Rolling
        iii. Pubescence

Dimensions of adaptation:

1. Crassulacean Acid Metabolism (CAM)
2. Metabolic changes via gene expression; synthesis of new protein types such as aquaporin, Ubiquitin, Late Embryonic Abundant protein.

From the cellular level, emergence of water deficit results in the decrease in the cellular water content, leading to shrinkage of cell and the relaxation of cell wall. Decrease in volume leads to increase in solute concentration, favouring reduced turgor pressure. Experimental results indicated that there is a synthesis of endogenous growth inhibitors (ABA and C_2H_2), changes in pH value and inorganic ion distribution. The consequence of these changes is the reduction in the expansion of leaf or leaf growth as expressed in the number of leafs or other growth parameters of the shoot. In the case of severe water deficit, reduction in total leaf area, increase senescence and leaf abscission accompany water deficit. If water deficit is mild the plant experiences reduction in transpiration rate via stomata closure increased heat dissipation and increasing resistance to liquid phase water flow.

At the crop level, reduced crop growth through stomatal regulation, as a result of water stress is reflected in reduced Leaf Area Index, thus compromising the radiant energy absorption capacity and its utilization efficiency (Radiant Energy Utilisation Efficiency). What is eventually experienced is reduced internal concentration of Carbon Dioxide and reduced Transpiration rate through the stomata. With reduced internal concentration of $C0_2$, carbon assimilation is equally affected reflecting in reduced Harvest Index and ultimately yield.

Where water a limiting factor, crop performance is expressed as:

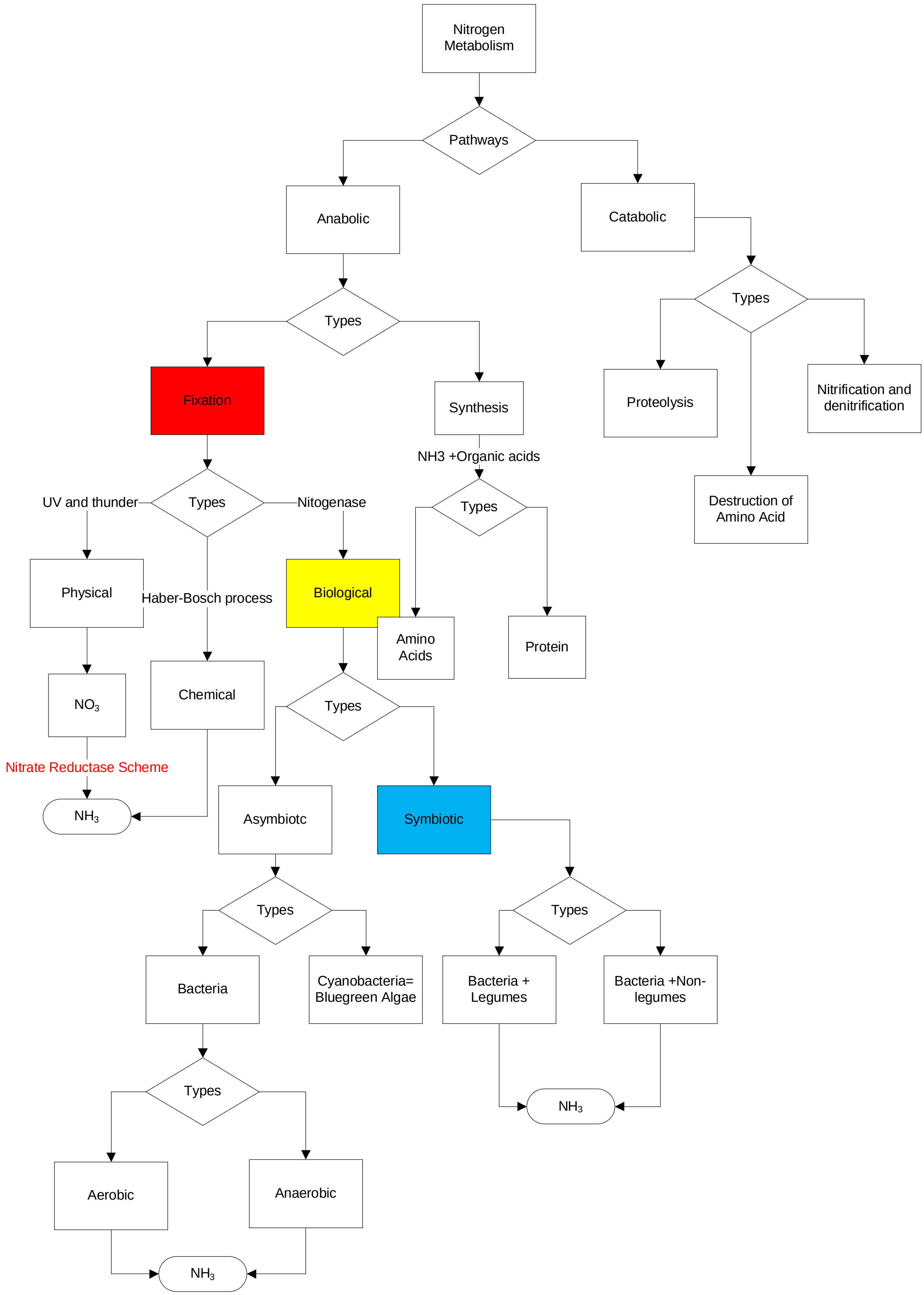
$$\mathbf{Y_E = W \times W_{Transp} \times WUE \times HI}$$

Where:

W: Amount of available water

W_{TRANSP}: Water Transpired
WUE: Water use efficiency
HI: Harvest Index
WUE: (Pa – Pi)/ 1.6 (VPi – VPa)
Where:
Pa: Partial Pressure Air
Pi: Partial Pressure Inside
VPi: Vapour Pressure Inside
VPa: Vapour Pressure Air
Total amount of water consists of the available and unavailable water in the soil. The available water in the soil is a function of the texture/structure and the volumetric water content. With soil water potential less than root water potential, the water content in the soil reaches the wilting point at which the water becomes unavailable to the plant. Conversely, with increasing wetting of the soil water, soil water potential increases, becoming more available to the plant. The volumetric water content increases up to a point at which drainage of water against gravity cannot be avoided, the field capacity. The colloidal contents of the soil predispose the water to be adhered to it, thus making water available to plants. Interrelationship between soil, plant and the atmosphere is expressed conceptually via Soil-Plant-Atmosphere Continuum.
Physiologically, water use efficiency is the ratio between assimilation of carbon and transpiration. Factors responsible for increasing water use efficiency could be deduced from the equation above; decreasing partial pressure of carbon dioxide inside the cell will increase the partial pressure gradient between the leaf plant and the atmosphere, increasing carbon assimilation, assuming carbon assimilatory capacity is non-limiting in the plant. Another option is to increase the vapour pressure in the atmosphere, by increasing ambient temperature. This will minimize transpiration flux from the plant since in most cases the vapour pressure in the plant is more than that of the ambient atmosphere. Increasing stomatal conductance linearly increases transpiration but response of carbon assimilation is curvilinear. Initially, carbon assimilation responds linearly, when carbon concentration is no more limiting the curve reaches a plateau.
Transpiration is constrained physically and physiologically. The physical forces at play in evaporation are expressed in the Ficks equation as indicated above.
Concentration of gases is better expressed as partial pressure, while the between gases is quite difficult to express, the whole equation is better expressed as changed in partial pressure of gases, while the distance and diffusion coefficient is both expressed as diffusion coefficient (g). Physiologically, evaporation is regulated by stomatal aperture, which is equally dependent on certain environmental factors. Light affects photosynthesis, which leads to reduction in partial pressure of carbon dioxide inside the cell, leading to negative feedback loop for the opening of the stomata. Increase temperature affects rate of photosynthesis, displaying the aforementioned reaction. Alternatively, with an increase in temperature the rate of transpiration increases, reducing leaf water potential and turgor, eventually resulting in stomatal closure. Reduced soil water potential equally result in reduction in leaf water potential, increasing formation of ABA and the eventual closure of stomata.

Nitrogen Metabolism -nitrogen fixation



Nitrogen Metabolism
Pathways
Anabolic
Catabolic
Types
Types
Fixation
Synthesis
Proteolysis
Nitrification and denitrification
NH3 +Organic acids
Destruction of Amino Acid
UV and thunder
Types
Nitogenase
Types
Physical
Haber-Bosch process
Biological
Amino Acids
Protein
NO_3
Chemical
Types
Nitrate Reductase Scheme
NH_3
Asymbiotc
Symbiotic
Types
Types
Bacteria
Cyanobacteria= Bluegreen Algae
Bacteria + Legumes
Bacteria +Non-legumes
Types
NH_3
Aerobic
Anaerobic
NH_3

There are anabolic and catabolic pathways in nitrogen metabolism.

Anabolic metabolism:

1. Nitrogen Fixation
    a. Physical
    b. Industrial
    c. Biological: This process is mediated via the action of nitrogenase.
        i. Asymbiotic(Free living)
            1. Bacteria
                a. Aerobic
                    i. Obligate, e.g. Azotobacter
                    ii. Facultative, e.g. Bacillius
                b. Anaerobic (Photosynthetic, non-photosynthetic)
            2. Cyanobacteria (Phototrophs)
        ii. Symbiotic
            1. Bacteria
                a. With legumes (Rhizobium)
                b. Non legumes (Frankia)
            2. Non Bacteria
                a. Cyanobacteria with higher plant (Nostoc)
                b. Cyanobacteria with lower plants (Tiny water fern and anabaena)
2. Synthesis of nitrogen containing organic compounds; amino acid and protein.

During Nitrogen fixation, there is the conversion of gaseous nitrogen into nitrogenous salts. When nitrogen is fixed physically, the following process takes place:

$$N_2 + O_2 \longrightarrow 2NO$$
$$2NO + O_2 \longrightarrow 2NO_2$$
$$2NO_2 + H_20 \longrightarrow HNO_2 + HNO_3$$
$$HNO_3 + Ca^{2+} \longrightarrow Ca\,(NO_3)_2$$

The above reaction is mediated by UV and thunder. The inorganic NO3 formed from this process is further assimilated through the scheme represented below:

Nitrate Reductase Scheme

$$NO_3 \xrightarrow{1} NO_2 \xrightarrow{2} (NOH)_2 \xrightarrow{3} NH_2OH \xrightarrow{4} NH_3$$

1- Nitrate Reductase
2- Nitrite Reductase
3- Hyponitrite Reductase
4- Hydroxylamine Reductase

When the above process is under industrial setting at high temperature and pressure, a process known as the Haber-Bosch process, it is referred to as industrial fixation of Nitrogen.
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In agricultural production, the presence of symbiotic bacteria with cultivated crop is highly important, must especially in mixed cropping system for sustainable agriculture. They are a veritable source for nitrogen in the soil. The mechanism of the symbiotic relationship between legumes and nitrogen fixing bacteria is as follows:

1. Host recognition by bacteria
2. Influx of microorganism into the host plant via the root hair
3. Migration of the microorganism into infestation thread
4. Formation of bacteriod
5. Production of leghaemoglobin

Nitrogen Forms

Parameters for comparison	**$N0_3$**	**NH_4**
Economic cost	More	Lesser
Predominant form absorbed	More	Lesser
Mobility	Yes	Immobile
Susceptibility to loss types: • Leaching • Denitrification • Volatization • Immobilisation	 Yes No No No	 No Yes Yes Yes
Effect on soil chemical property	Alkalisation	Acidification
Uptake Mechanism • Active • Induced • Type	 Yes Yes Biphasic	 Yes/No Constitutive Multiphasic
Toxicity effect on plant	No	Yes