

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, 45⁰ latitude

$$= 1.013 \text{ bar}$$

$$= 0.1013\text{MPa}$$

$$= 1.013 \times 10^5 \text{ Pa}$$

Water potential components:

$$\Phi_w = \phi_s + \phi_t + \phi_m + \phi_g$$

Where:

Φ_w – Water potential

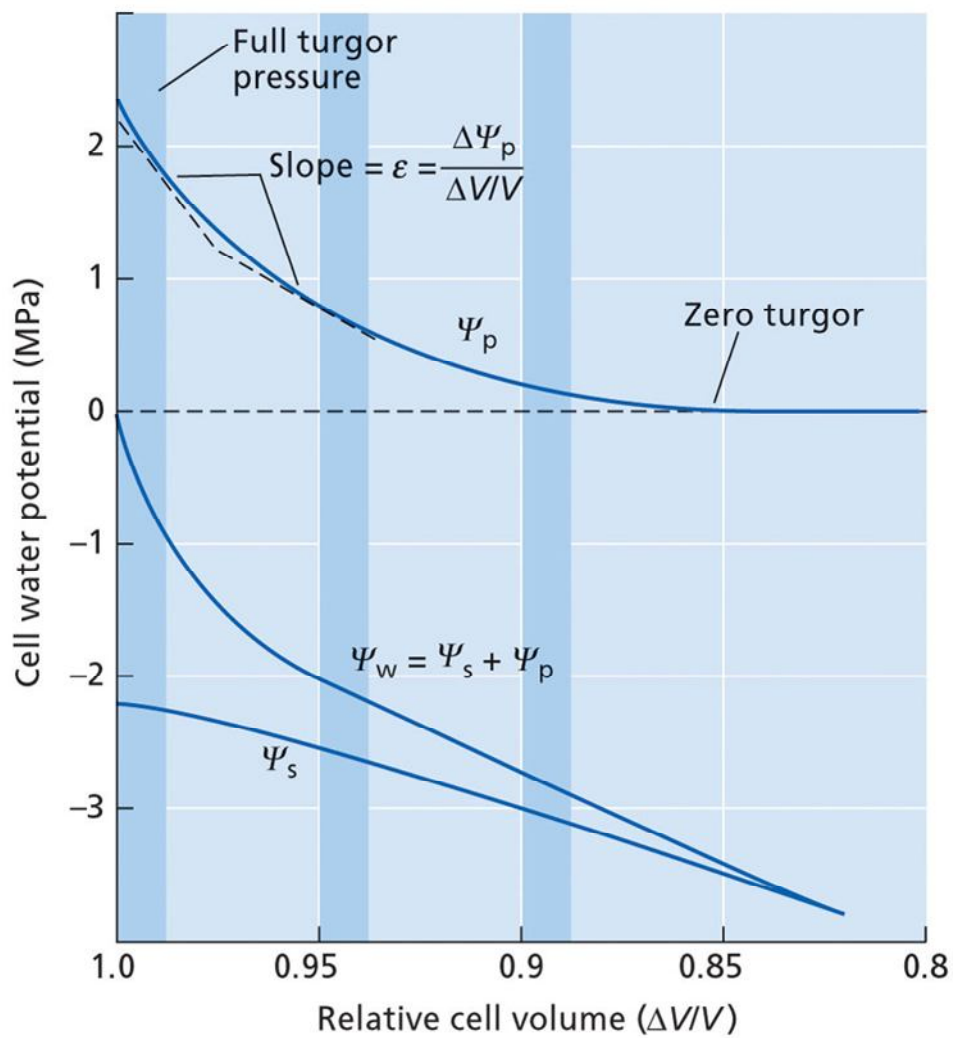
Φ_s – Solute potential

Φ_t – Turgor potential

Φ_m – Matrix potential

Φ_g – Gravitational potential

Interrelationships among the water potential parameters as illustrated in Hofler Diagram



PLANT PHYSIOLOGY, Third Edition, Figure 3.10 © 2002 Sinauer Associates, Inc.

- Slope of Ψ_p curve yields the volumetric elastic modulus (ϵ)

- 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	<p>Concentration gradient</p> <p>Fick's Law</p> $J_s = -\Delta s \Delta c / \Delta x$ <p>Where; J_s – Rate of solute diffusion</p> <p>Δs – Diffusion coefficient, measures ease of substance movement via a medium</p> <p>$\Delta c / \Delta x$ – Concentration gradient</p> <p>Δc – Difference in concentration</p> <p>Δx – Difference in distance</p>
Bulk Flow	<p>Pressure gradient</p> $\text{Volume} = \pi r^4 \Delta P / \Delta x / 8 \eta$ <p>Where:</p> <p>Volume - Flow rate</p> <p>r – Radius</p>

	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 $\phi_w = \phi_s + \phi_p$	<ul style="list-style-type: none"> ○ Apoplast ○ Symplast ○ Trans-membrane
Plant	Long distance transport (Cohesion-tension)	Pressure gradient	Xylem
Plant-Atmosphere	Transpirational pull of water	Gradient of water vapour concentration (Diffusion)	<ul style="list-style-type: none"> ○ Stomata ○ Cuticle ○ 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 leaves 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 CO_2 , carbon assimilation is equally affected reflecting in reduced Harvest Index and ultimately yield.

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

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

Where:

W: Amount of available water

W_{TRANSP} : Water Transpired

WUE: Water use efficiency

HI: Harvest Index

$$WUE: (P_a - P_i) / 1.6 (VP_i - VPa)$$

Where:

P_a : Partial Pressure Air

P_i : Partial Pressure Inside

VP_i : Vapour Pressure Inside

VP_a : Vapour Pressure Air

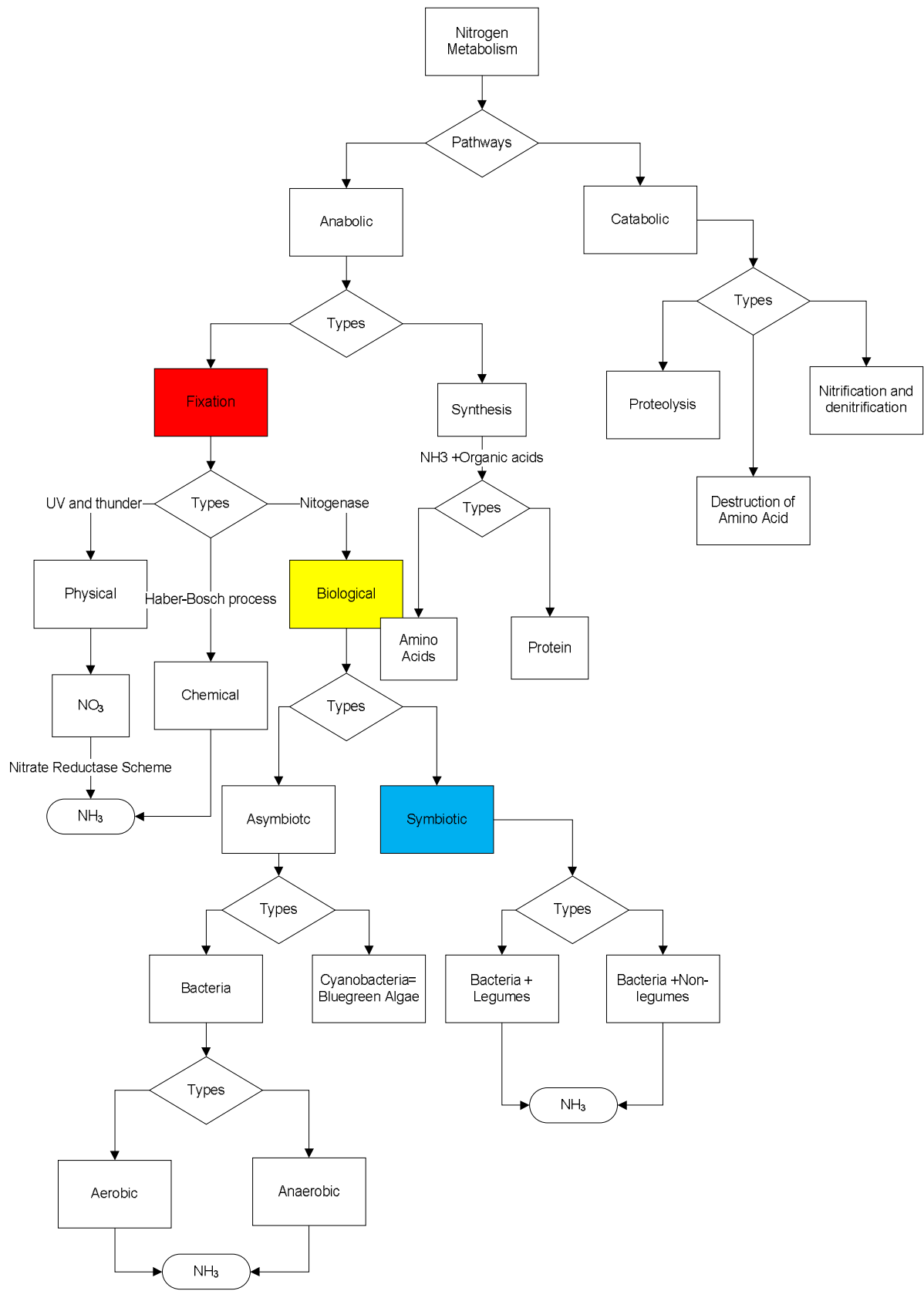
Total amount of water consists of the available and unavailable water in the soil. The available water in the soil is a function of the texture/structure and the volumetric water content. With soil water potential less than root water potential, the water content in the soil reaches the wilting point 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



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. Bacillus

b. Anaerobic (Photosynthetic, non-photosynthetic)

2. Cyanobacteria (Phototrophs)

ii. Symbiotic

1. Bacteria

a. With legumes (Rhizobium)

b. Non legumes (Frankia)

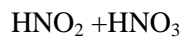
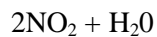
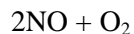
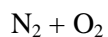
2. Non Bacteria

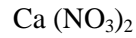
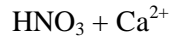
a. Cyanobacteria with higher plant (Nostoc)

b. Cyanobacteria with lower plants (Tiny water fern and anabaena)

2. Synthesis of nitrogen containing organic compounds; amino acid and protein.

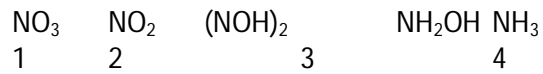
During Nitrogen fixation, there is the conversion of gaseous nitrogen into nitrogenous salts. When nitrogen is fixed physically, the following process takes place:





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



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.

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	NO_3	NH_4
Economic cost	More	Lesser
Predominant form absorbed	More	Lesser
Mobility	Yes	Immobile
Susceptibility to loss types: <ul style="list-style-type: none"> • Leaching • Denitrification • Volatization • Immobilisation 	Yes No No No	No Yes Yes Yes
Effect on soil chemical property	Alkalisiation	Acidification
Uptake Mechanism <ul style="list-style-type: none"> • Active • Induced • Type 	Yes Yes Biphasic	Yes/No Constitutive Multiphasic
Toxicity effect on plant	No	Yes