Movement of ions soils to roots - Mass flow, diffusion, root interception and contact exchange

Movement of ions from soils to roots-

For the ions to be absorbed by plants roots, they must come in contact with the root surface. This generally takes place by three ways in which the nutrient ions in soil may reach the root surface

1. Movement of ions by mass movement in the soil solution – Mass flow.
2. Diffusion of ions in the soil solution – Diffusion.
3. Root interception and contact exchange.

I. **Mass flow**:

Movement of ions from the soil solution to the surface of roots is accomplished largely by mass flow and diffusion. Mass flow, a convective process occurs when plant nutrient ions and other dissolved substances are transported in the flow of water to the root in en mass that results from transpirational water uptake by the root. This depends on the rate of water flow or the water consumption of plants. Mass flow supplies an over abundance of calcium, magnesium is many soils and the most mobile nutrients such as N and S.

Factors affecting mass flow As mass flow involves nutrient movement with water, both the amount of water and volume of soil it comes from, affect the mass flow.

1) **Soil moisture content**: In dry soil, no mass flow of nutrients occurs because there is no water to carry them to the plant roots. .
2) **Soil temperature**: Low temperature reduces transpiration and evaporation; resultantly reduced water flux occurs across the roots.
3) **Size of the root system**: affects the water uptake and consequential mass flow. Root density, however is much less critical for nutrient supply by mass flow than for root interception and diffusion.

II. Diffusion:

Most of the phosphorus, potassium (relatively immobile) and micronutrients (present in small quantities), move to root by diffusion. Diffusion occurs when an ion moves from an area of high concentration to one of low concentration by random thermal motion. As plant roots absorb nutrients from the surrounding soil solution, a diffusion gradient is set up. A high root absorbing power results in a high diffusion gradient favouring ion transport. The three principal factors influencing the movement of nutrients into the roots are the diffusion coefficient, concentration of the nutrient in soil solution and the buffering capacity of the solid phase to release nutrients into the soil solutions.

Soil moisture is a major factor that affects the relative significance of the mass flow and diffusion. Diffusion becomes progressively less important as the moisture content decreases.

The amount of nutrient ion diffusing across a unit area in unit time (F) with a concentration gradient, dc/dx is given for steady state diffusion by

Fick's first law of diffusion $F = -D\,(dc/dx)$

D is the diffusion coefficient in the soil with units cm^2/s

The minus sign indicates movement from higher to lower concentration.

Factors affecting diffusion

1. **Soil water:** The higher the moisture content, higher will be the diffusion coefficient, until the moisture content reaches saturation.
2. **Soil compaction:** Incremental increase in the soil compaction at the same moisture content leads to the exclusion of air; soil particles come closer, the continuity of moisture flows increases, path to be traversed by the ion by diffusion becomes less tortuous and resultantly, the diffusion coefficient exhibits an increase.
3. **Temperature:** The rate of chemical reaction doubles for every $10^{o}C$ rise in temperature. The increase in temperature increases the effective diffusion coefficient of a nutrient ion.
4. **Chemical amendments**: Chemical treatments modify the concentration of the nutrient ions in soil solution as given below
   - Amelioration of soil acidity through liming raises the pH of the soil. Thus, diffusion coefficient of cations decreases and anion increases as a result of liming.
   - Application of gypsum to a sodic soil reduces the soil pH, as a result of which diffusion coefficient raises.
   - Organic manures act as the store house of nutrients. In addition, they release low molecular

weight organic substances which have the ability to form complexes with cations. This increases the diffusion coefficient of nutrients.

III. **Root interception and ion exchange**: Jenny and Overstreet (1939) propounded the 'theory of contact exchange'. Theory of contact exchange rests on the concept of overlapping oscillation spaces of adsorbed ions, or redistribution within intermingling electric double layers. Contact exchange as a mechanism for nutrient movement could be pictured as

$$\text{Clay} \quad M^{+} \quad + \quad H^{+} - \text{Root} \quad \rightarrow \text{Clay} - H^{+} \quad + \quad M^{+} \quad \text{Root}$$

and modelled as

$$\text{Clay} \quad M+ \quad H+ \quad \text{Root}$$

Cation exchange theory on further refining gave rise to the concept of 'root interception' a term coined by Stanley A Barber, which is used to describe the soil nutrients at the root surface that do not have to move to the interface to be positionally available for absorption, but are approached by the root itself in the soil.

As the root system develops and exploits the soil more completely, soil solution and soil surfaces retaining the adsorbed ions are exposed to the root mass and absorption of these ions by the contact exchange mechanism is accomplished. The quantity of nutrients that can come in direct contact with the plant roots is the amount in volume of soil equal to the volume of roots. It can be assumed that roots usually occupy 1 % or less of the soil. It is estimated that roots would contact a maximum of 3 % of the available nutrients in the soil.

It has been observed that plant roots also possess the cation exchange property, ranging from 10 to 100 Cmol/ kg roots. This property could be due to the –COOH groups of pectic substances of cell wall. Legumes have high root CEC and absorb more divalent cations, monocots have low root CEC and absorb more of monovalent cations like K^{+}. Ions attached to the surface of roots may exchange with those held on the surface of clays and organic colliods because of the contact between roots and soil particles. The mucilaginous gel around root surface could serve as contact complex. The presence of mycorrhiza, a symbiotic association between fungi and the roots of plants, enhances the uptake of nutrients particularly phosphorus.