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Review Article

The Mechanisms of Absorption and Nutrients Transport in Plants: A Review

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ABSTRACT

Plants need various essential nutrients to survive and to develop adequately. These nutrients are needed in sufficient amount and accessible for plant take-up. Furthermore, nutritional necessities change from one plant species to another and from one plant growth stage to another. Roots transit nutrients further into the plant. It is not uncommon for plant roots to develop in soils with under 3% of accessible nutrients. They need more nutrients including calcium and magnesium, for their normal life cycle, yet these soils require modest quantities of other nutrients, such as potassium and phosphorus. The accessibility of nutrients facilitates its transfer from soil to the plant roots through an assortment of mechanisms. While, the nutrient transit depends on the mass flow, diffusion and root interception. The paper aim to explore the current state of the art in the world of nutrient transport systems for plant survival. The structures involved, mechanism of absorption, and ion exchange mechanism are discussed. Factors affecting plant nutrient uptake, in relation to the percentage of nutrients in the soil solution, and some characteristics of the ion transport mechanisms that directly influence soil-based nutrient uptake processes are also highlighted.

Keywords: Plant roots, Absorption, Nutrients, Nutritional necessities.

Introduction

Actually, there are 118 or so separate elements. $Fe^{(2+)}$ is the most abundant element situated on the earth than other elements.[1] Basic elements are considered as those components that have essential significance for the normal activities and establishment of plant. Nutrient deficiency alters the normal growth of plants which can lead to the plant diseases.[2] These elements which promote growth and development can be divided in two categories : macronutrients (needed in large amounts) and micronutrients (needed in smaller amount).[3] Additionally, plants produce other components, the inadequacy of which is not at risk to cause any ailing impact on plant. Carbon, hydrogen, nitrogen, arsenic, potassium, calcium, sulphur, magnesium, and iron are macronutrients. Manganese, zinc, boron, copper, molybdenum, and cobalt are among the micronutrients. Sodium, aluminum, silicon, chlorine, gallium, among others are non-essential materials.[4] They are present in organic or inorganic form in aqueous solution of soil which are found in form of ion in solution or some of them are adhered with the particle of silicon. Plants take these ions from soil solution which causes depletion of these ions in soil solution. This depletion alters the root's uptake of minerals which adheres to soil particles.

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This process is known as an ion-exchange process. This process is occurred because of the process of ion exchange as well as an exchange of ions by carbonic acid mechanisms.[5]

Structures involved in absorption

The aquatic plant's body acts as an absorbing surface, therefore minerals uptake does not need any kind of absorption process. However, the large root system help terrestrial plants to secure the process.[6,7] A radioactive isotope short-term experiments labelling show that the meristematic root regions absorb more ions than any other region.[8] Roots play one of the biggest roles in plant survival. They are not only supply anchorage but also double up as the main nutrient uptake and storage system. Although some scientists agree that storage falls within the realm of internal metabolic category, it is impossible to address the absorption of minerals without reference to storage.[9] Root morphology system is very complex and dynamic to ensure plants nutrient supplied with both water and nutrients. The morphology describes some parameters such as the root radius, length, volume, and physical nature (distribution in the soil).[10] Regarding the root system, morphological characteristics can be classified into four categories based on root distribution, root topology, root structure, and root morphology.[11] A large part of root morphology/structure is impacted by the availability of symbiotic microorganisms and nutrients. Plant nutrients are utilized through the development of plant meristematic tissues and they are ultimately absorbed through the active transport of xylem elements.[10] They transit upward from the xylem components along with the transpiration stream and extend to all other regions with branches and sub-branches. Root hair cells help to increase the uptake of water and other nutrients.[12] These nutrients are transported from one cell to another by an osmotic process through the chloroplast pathway. As the nutrient solution goes from higher to lower ionic amounts of nutrients, the solution within the root hair cells

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becomes diluted.[13] This suggests a pressure difference exists between the root hair cell and the adjacent root cells, as a result water flows from the root hair cell to the surrounding areas by a process of osmosis before reaching the xylem tube for transport.

Mineral ions often flow via the available free space of the roots system, although the cell cytoplasm needs various types of ions to join.[14] The acquisition of nitrogen (N) and sulfur (S) is of special significance since the synthesis of amino acids and proteins includes these elements. The main sources of N and S used by plants in nature are nitrate (NO^{3-}), ammonium (NH^{4+}), and sulfate (SO_4^{2-}). However, those nutrient products are not dispersed equally in the soil system. The amounts of soil nutrients fluctuate due to climate change, considering the application of fertilizers.[15] As plant nutrient ions migrate through the root cell, they reach the inert cell wall to penetrate the cell membranes; there are several delivery systems, some passively transmitted and others actively transported through the cell wall (using ATP energy). The charged Cl^- and Br^- particles are shared despite the interruption of electrolytic equilibrium; this theory describes the effect of bound ions or lack of diffusion accumulating mainly on the interior surface of the outside surface. The process is named after F.G. Donnan.[16] This will potentially create a difference across the membrane at either membrane boundary, where there is a non-diffusing negative potential, onto which ions would migrate. As a result, electrochemical equilibrium would be achieved; this means that the number of chemical ions will not be exactly the same on the inside and on the outside.[17] Therefore, as an electrical imbalance occurs due to the absorbed charges, a diffusion imbalance is generated.

Transport of nutrient from soil to root surface

Nutrients are transmitted from soil to plant roots via one of three mechanisms: mass flow ,diffusion, or root interception. Mass flow is defined as the convective passage of nutrients dissolved in plants when the plant takes up water for transpiration.[18] Diffusion, in turn, is the movement of minerals from higher to lower concentration regions. In this context, diffusion is the transfer of nutrients to the root surface following a concentration change. Finally, root interception describes the uptake of minerals from the root surface through contact with soil colloids.[17]

The three transfer mechanisms are crucial to the transport of micro-nutrients for all conditions. A number of plant physiologists have studied the relevance of each mechanism, to understand the impact on nutrient uptake. In most cases, however, minerals move through diffusion, mass flow, or both.[19] Root interception is considered to be a building block of the diffusion mechanism. The input of root interception in mineral uptake is rather negligible for most minerals.

Having collected and tested over a hundred soil samples, calcium and magnesium nutrients were predominantly absorbed through root interception and that low quantities of potassium and phosphorous also were supplied through this mechanism.[20]

Mass flow in turn was involved in the transfer of large quantities of calcium, magnesium, and even potassium in some soil samples but not in particularly larger quantities. Similarly, diffusion is the main mechanism used for the absorption of significant amounts of potassium and phosphorous. Bagheri concludes by stressing how all three mechanisms are necessary for the survival of plant.[21]

Mass Flow

The process is a soil-plant transfer mechanism characterized the movement of nutrients through available water in the soil (Figure 1). The ions move from soil to the root system using the convective flow.[11] The relative influence of mass flow on mineral uptake depends on the time of day, the age of the plant, and the plant species. While, mass flux contributes significantly to the uptake of magnesium and calcium, it provides negligible amounts of potassium. According to,[22] mass flow is affected by:

- Capillary properties of the soil;
- Gravitational water, for example after rainfall, when nutrients are likely carried further from roots;
- Plant water use;
- Release rate into solution, solution parameters and buffering capacity.

In practice, mass flow uptake contributions are determined by multiplying the overall concentration of ions in the water by the total amount of water taken up in the plant. It should be noted, however, that the concentration of minerals plays an important role in the amounts of mineral uptake. The more minerals are available in the soil profile, the more minerals will be moved to the uptake system.[23] In turn, the accessibility of water in the soil system significantly reduces the transfer of minerals by mass flow; a condition that leads to the closure of plant stomata and further reduction in mass flow and transpiration.[24]

Root Interception

This system of transfer mainly relies on root growth to intercept nutrients literally (Figure 2). According to some plant physiologists, root interception as a soil-plant transfer mechanism is not well understood.[25]

This is particularly true since root interception has no particular direct exchange between plant roots and soil particles in the absence of liquid environment.

This transfer system is influenced by soil structure, as compact soil profiles can be a hindrance to root growth. It has been noted that root interception moves only a negligible amounts of calcium and magnesium.[26]

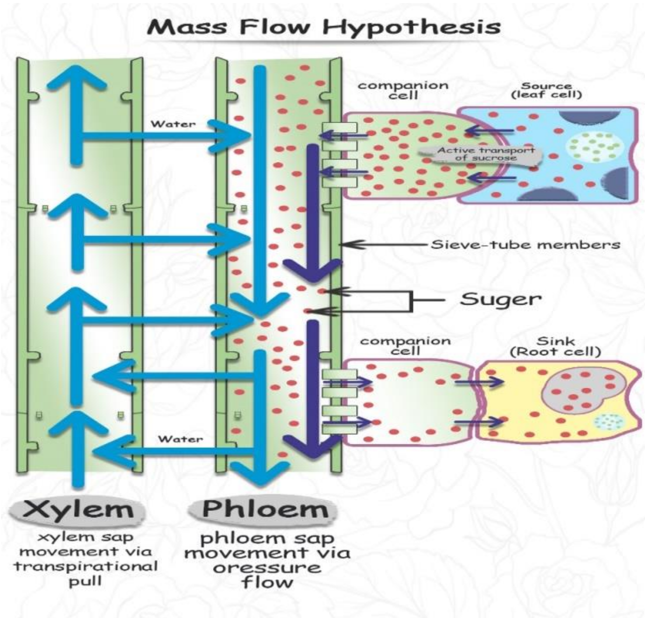

Figure 1: Mass flow mechanism hypothesis

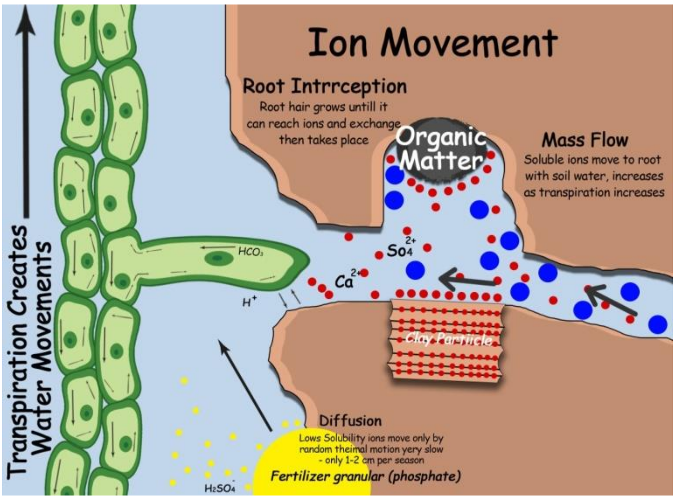

Figure 2: Ion Root Interception movement mechanism

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Diffusion

The diffusion occurs when there is a concentration gradient between the soil profile and the plant's root system. In particular, when a mineral's concentration in plant's root system decreases, creates a depletion zone.[27] Due to the difference in concentration, nutrients will naturally move to the region of lower concentration to reach equilibrium. Diffusion is the principal transfer mechanism for phosphorus and potassium uptake.[28] It is influenced by soil water content, solution nutrient concentration, temperature, and tortuosity. The total amount of nutrients reaching the root by diffusion is calculated by finding the difference between the total nutrients absorbed and the amount displaced by root interception plus the total mass flow.[28]

Mechanism of Absorption

It has always been assumed that the absorption of mineral salts occurs simultaneously with the absorption of liquids. But it is now understood that there are two distinct mechanisms for the absorption of mineral salts and the absorption of water. In the form of ions, mineral salts are removed from the soil solution, they are mainly consumed at the tips by the meristematic regions of the roots.[29]

The cell membrane of root cells cannot allows the passage of all ions. In incomparable quantities, it is not as if all similar nutrient molecules are absorbed, but the ions of the nutrient compounds are absorbed unevenly. The initial step in the absorption of essential nutrients is the process of ion exchange, which requires no energy.[30] This process of extracting essential nutrients takes two forms: passive and active.

Passive transport: If the concentration of mineral salts in the external solution is higher than that of the root cell sap, the mineral salts are absorbed by a basic diffusion mechanism along the concentration gradient. This is referred to as passive uptake since no metabolic energy consumption is required.[31]

Active transport: Large volumes of chemical nutrient ions have been found to be accumulated by cell sap in plants against the concentration gradient. The deposition of minerals by the electrochemical gradient is an efficient procedure that takes the depletion of metabolic energy by respiration. The successful uptake of mineral salts requires the functioning of a mineral salt as a transporter compound in the plasma membrane of cells.[32]

Ion Exchange Mechanism

The colloidal characteristics of soil clay minerals are in interactions with bean roots. Many of the nutrients ions are attached to colloidal soil, including certain Na, K, and others. Root cells to release hydrogen ions, which have been positively charged. These ions can quickly be substituted by positive charges containing ions like K^+ and Na^+ ions that are linked to clay minerals. The positive containing ions are then given access to the root system for the diffusion of the required ion.[33] However, while not complandely fixed, the relative randentive power of the clay particles is in the order of H^+>Ca^{2+}>Ng^{2+}>K^+>NH^{4+}>Na^+.

But any cation ion presents on such clay particles is capable of replacing hydrogen ions. Hydrogen ions, however, tend to be able to substitute some bound ions for clay particles, although there is a preference for ions to be released. Since hydrogen ions have greater affinity, they can quickly replace all of the ions above. Both positive and negative ion appears to be adsorbed on the cell wall surfaces and exchanged with ions found in the solution of the soil.[34] This method of interaction in solution is known as an ion-exchange between bound ions and ions. In the ecosystem, plantations use inorganic nutrients to generate an important metabolites. Nutrient efficiency improves plant health and yield. The acquisition of nitrogen (N), as well as sulphur (S), is of particular importance, as the synthesis of amino acids and proteins requires these elements. The main sources of N and S used by plants in nature are nitrate (NO^{3-}), ammonium (NH^{4+}), and sulphate (SO_4^{2}-).[35]

Carbonic acid ion exchange mechanism

The roots respire continuously, day or night, and discharge vast amounts of CO_2, which, when dissolved in soil moisture, generates carbonic acid. They break directly into H^+ and bicarbonate ions (HCO_3^-). So, ion of hydrogen generated can be transferred with some bound cations on particle of clay to keep the connected cations accessible to the roots.[36] While the preceding processes were recommended like hypotheses, it is an evident that not only CO_2 is emitted, on the other hand, ions of hydrogen are often secranded by rising roots. The root supplies hydrogen ions for the processes of interaction of both carbonic acid ions and contact ions. Similarly, anions such as OH^- ions are also substituted for adsorbed anions.[37]

The carrier concept

Unrestricted mineral ions easily cross The cell membrane. However, in order to create a complex of carrier ions that can cross the membrane, some mixture present in the membrane acts as a transporter, binding to the mineral ions. This complex allows ions to be released into the cell on the internal side of the membrane, while the carriers return to the external surface to retrieve other ions. There are two types of theories that describe active salt uptake based on the definition of a transporter without agreement between them.[38]

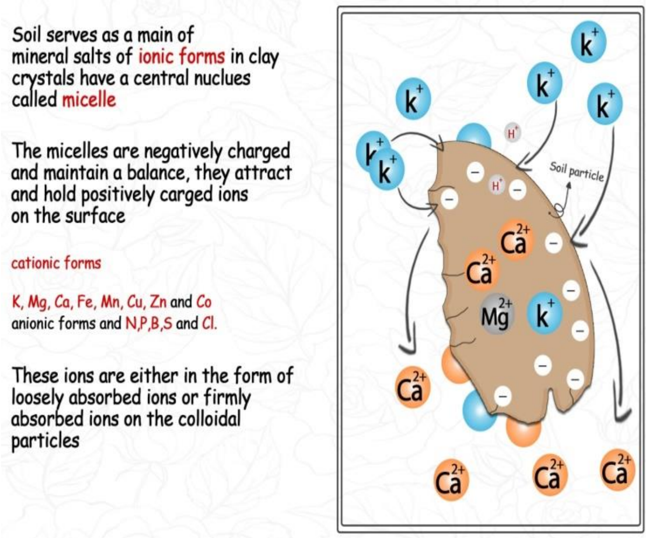

Figure 3: Ion Exchange theory

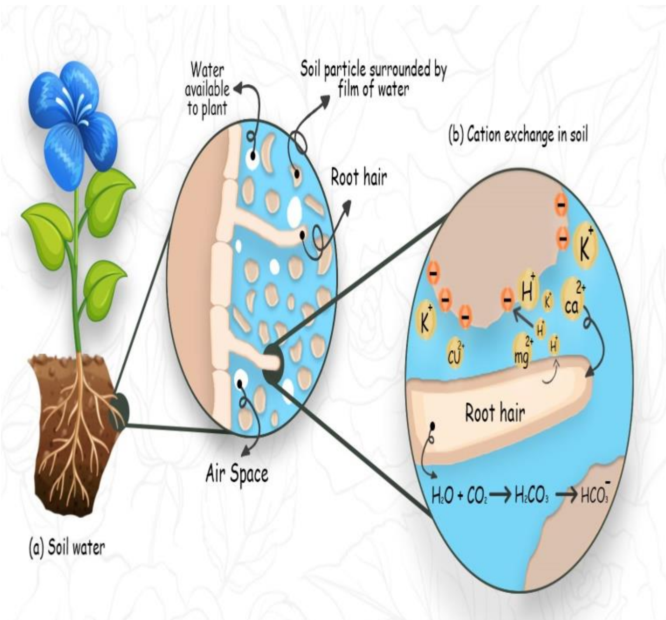

Figure 4: Carbonic acid ion exchange mechanism

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Lundegardh and Burstrom Theory (1933)

Lundegårdh et al. [39] found a close link between anion uptake and respiration. Thus, the rate of ion exchange increases when a plant moves from an aqueous medium to a mineral solution. This improvement in the rate of mineral ion exchange compared to adequate exchange has been called the anion exchange.[40]

Lundegårdh et al.[41] suggested the cytochrome pump hypothesis, which is based on the following assumptions.[42]

a. Anions are consumed by an active mechanism through the cytochrome chain. (Cytochromes are porphyrin-ion proteins that act as enzymes and assist in the choice transition during respiration).

b. Cations are ingested passively. In line with this theory,

c. Dehydrogenase transformations on the internal surface of the membrane release protons (H^+) and electrons (e-).

d. Electrons migrate out of the cytochrome chain beyond the membrane, so that the Fe in the cytochrome is reduced (Fe^{2+}) on the surface layer and oxidised (Fe^{3+}) on the inner layer.

e. On the external layer, the modified cytochrome is metabolised by oxygen which removes the electron (e-) and takes on an anion (A^-).

f. Thus, the removed electron combines with H^+ and oxygen to create water.

g. The anion (A^-) continues its path through the cytochrome chain to the interior.

h. The oxidised cytochrome is decreased on the internal surface by taking an electron generated by dehydrogenase reactions and releasing the anion (A^-).

i. A cation (M) slowly moves from the outside to the inside to release the anion as a result of the anion uptake.

j. By gaining an electron produced by the dehydrogenase transformations and releasing the anion, the hydrolysed cytochrome is decreased on the inner surface (A).

k. As a result of anion uptake, a cation (M) gradually moves from the outside inwards to oppose the anion.

Bennert – Clark's protein Lecithin Theory

In 1856, Bennert-Clark proposed that the transporter could be a protein associated with the phosphatide called lecithin since cell membranes are mainly made up of phospholipids and proteins and some enzymes appear to be present. He likewise proposed that the quantity of known categories of cations and anions related to the presence of various phosphatides.[43]

The phosphate group of the phosphatide is called the active cation-binding centre, whose is considered to be the simple choline group.[44] The ions are released by the decay of lecithin by the enzyme lecithinase on the inner surface of the membrane. The restoration of the phosphatidic acid and choline component of the carrier lecithin takes place in the presence of choline acandylase and choline esterase and ATP enzymes. The latter serves as an electricity source.

Factor affecting on the uptake of plants nutrients:

Soil aeration

In many other cases, without oxygen, living cells cannot survive. Since roots consist of a large number of living cells, their metabolic processes and development require large amounts of energy. Oxygen is therefore needed to produce energy-rich components via the biological process of oxidation. Insufficient soil aeration decreases the root's ability to take-up the nutrients needed. There is so little air in waterlogged soils or soils with a high clay content that in such circumstances, plant roots exposed to the environment have a lack of oxygen and the uptake of mineral plant nutrients is significantly affected. The alteration of nutrient acquisition due to the impact of respiratory toxins on roots clearly demonstrates that nutrient acquisition is an energy-dependent mechanism.[45]

Temperature of soil

Soil temperature is a major factor in the physiological functions of the roots and also affects the movement of nutrients from the soil solution. If there is a depletion of soil temperature, mineral uptake can be significantly reduced. Otherwise, the rate of uptake still increases, but to these thresholds, with increasing temperature. The radical differences in uptake rate due to temperature changes mean that the mechanism is enzyme dependent.[46]

Soil pH

The level of ionisation of nutrients, as well as other nutrients, depends on the hydrogen ion concentration of the soil solution. A reasonable pH, in other circumstances, gives priority to the absorption of monovalent types of nutrients. Therefore, the soil pH has not only a profound impact on the rate, but more importantly on the sequence of nutrient ion absorption. This function is often due to its effect on the cellular materials involved in uptake, which further suggests that proteins are important in the uptake of plant nutrient ions. This is why it is so necessary for agriculture to maintain a correct soil pH. For agriculture, a soil that is too acidic or too alkaline is practically worthless. Such soils will remain wastelands until the concept of pH is restored.[47]

Amount nutrient in soil solution:

Usually the abundance of elements and their components in soil water is much lower than that found in cell sap. This suggests that the uptake of ions is against the concentration gradient. The relative concentration of electrolytes present in the plant cell and the soil solution tends to give the rate of uptake. Seawater contains much higher amounts of salt than fresh water. Terrestrial plants that are adapted to grow in natural water soils perish in seawater when more ions take over from the salt water; they are biologically dry. In contrast, marine plant cells adapted to these waters have much more ionic material than that present in seawater.[48] Here too, even against a concentration gradient, charges are extracted. The rate of ion uptake is very strong and depends on the concentration of the soil solution. In dilute solutions, roots generally consume higher concentrations of ions at a slower rate than in solutions of comparatively high concentration. It is not clear how dilution specifically enhances rapid uptake, but it is a reality.[49]

In varying amounts, the soil solution contains a wide range of ions. As roots consume mineral nutrients, minerals of one type present in the soil water either promote or hinder the accumulation of other ions. This is called ion antagonism. On the other hand, the uptake of certain other types of ions is increased by a certain type of ion. Such a process is known as ion-facilitated absorption. Epstein showed that the presence of divalent calcium and magnesium ions antagonises the uptake of K and Fe. Similarly, $CaCl_2$ was found to reduce the uptake of the Cu^{2+} ion and protect plants from copper toxicity. In contrast, sodium chloride was found to promote the uptake of a wide rang of ions. On the basis of transport molecules, these types of ionic interactions leading to antagonistic or facilitated uptake are clarified. Similar ions have different transport proteins or transporters.[50]

Due to the single binding site, ionic antipathy occurs for any ion that must compare to all other ions for the same sites. In contrast, the binding of a particular ion to carrier molecules allows the binding of a specific ion and increases the uptake of that ion. Therefore, a regulated mineral is very important, otherwise more than one form of ion is taken up by the roots, or the involvement of another type of ion may limit the acquisition of the appropriate ion.

Some Characteristics of ion transport mechanisms of plant

Unequal absorption and specificity of ion

A mixture of separate elements with approximately the same mole fraction in the form of a solution containing a buffer is added to the root zone, some ions are absorbed in higher concentrations than others, the rest are absorbed in trace differences. This illustrates the uneven absorption and also the precision. Specific cells consume certain ions at a specific stage of their growth because they are necessary for their metabolism. Precision is demanded by the specifications of the cell or tissue.[51] The pH of the external environment continues to remain more or less neutral. This is certainly due to ion exchange. This can be demonstrated by immersing a tomato plant with its roots in a dilute NaCl solution. After some time, certain ions such as K and Ca^{2+} that were not present before are found in the external solution. Furthermore, the preferential uptake specifically shows the role of particular transporters in the ion uptake process.[52]

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Salt Accumulation
Analysis of the sum of trace elements in the plant cell and in the external solution suggests that the relative abundance of the different components in the cell sap is higher than in the aqueous phase. The same view is also reinforced by the use of radioactive isotopes as traces where these ions are stored or consumed against the concentration gradient.[53] The similar is explained in millivolts with respect to the determined biochemical potential. In the cytoplasm of Niandellas cell, Na^+ reveals a molecular strength of 72 mV, potassium demonstrates the difference of 40 mV and chlorine + 237 mV. The above results clearly imply that the concentration of Na is indeed very high in the external solution.[54] It can be passively diffused into the cell across the membrane along the usual pathway, but Na ions are expelled from the cell to preserve the chemical potential gradient and avoid unnecessary Na toxicity. In contrast, the movement of ICs (add the meaning of this abbr) is an upward path, as their intensity inside the cell is many times higher than outside. Ion flow and ion exctanction are attributed to the entry and exit of ions.[55]

Saturation Effect
If an excessive amount of a particular ion is introduced into a root system, ions are initially collected at a rapid rate, but the supply then remains relatively constant. Furthermore, this finding indicates that there is a fixed number of unique carrier sites for a given ion; the adsorption process will not be increased until the volume of carriers is increased, if all are charged with their accompanying charges. The adsorption rate will not be increased until and until the number of carriers, if all are charged with their respective ions, is increased.[53]

Mandabolic energy
For all metabolic processes, energy is needed. This can be measured by supplying the roots of the plant involved with systemic toxic substances such as KCN (Potassium cyanide), DNP (2,4-dinitrophenol), and rotenone. As long as the type of inhibiting compound is added, the ion supply decreases significantly, which means that energy is totally needed for the mineral supply. Mineral sorption to show whether mitochondrial energy is required for ion uptake or not.[56]

Apparent free space
When a crop receives a fixed concentration of radioactive charges, including $^{35}SO_4$ or ^{32}P, for about 30 minutes, without its roots being affected, it is possible to measure the cumulative amount of ions collected either by the root system or by measuring the amount of radioactivity remaining in the liquid delivered outside. Secondly, it appears to be a high level of radioactivity that could be rapidly calculated in the liquid when such a plant is converted to water. The difference between the maximum amount of radioactivity swallowed during the first incubation and the total volume of radioactivity reappearing in the water is, in fact, the amount of radioactivity ingested into the root of the plant.[57] The radioactivity that extends into the liquid is the number of nuclear particles that are taken up in the available spaces located in the cells of the root. Therefore, for ion diffusion, open spaces are free, and these spaces are called apparent free spaces. In the intercellular regions and cell walls, these openings are located in the roots; in general, measurements have revealed that the maximum defined AFS (add the meaning of this abbr) is high in relation to the total root mass. In SFAs, the movement of ions or water depends on a passive mechanism and concentration.[58]

Donnan's free space
In the outer area of the cytoplasm, a physiologist named Donnan pointed out that all cells contain a particular amount of large -ve carrier molecules. The space that is filled by such molecules is called the Donnan space. Ion pairs such as K^+ and Cl^- enter plant root cells in similar proportions to neutralise these charges. All K^+ ions are adsorbed onto negatively charged Donna molecules.[59] This adds to a higher negative charge within the cell. Thus, more K^+ ions move in and neutralise it. Lower concentrations of K^+ ions are also taken up. It is assumed that this mechanism is passive. In addition, some spaces are thought to be in the peripheral zone of the cytoplasm. It is assumed that the Donnan molecules are ureic acid molecules. Any of the large natural molecules present in the cytoplasm of plant cells currently have both charges. Where, then, is the Donnan space contained in the cell? The uptake of ions by the Donnan system is difficult to describe.

Conclusion

For their existence and proper growth, plants need various vital nutrients. These nutrients are needed in adequate quantities for proper plant growth and are made available for plants to absorb. Nutrient requirements vary from one plant species to another and during the different phases of plant growth. These nutrients are supplied to the roots. The roots are responsible for carrying these nutrients deeper into the plant. In some soils that have <3% available nutrients, plant roots grow. For their steady progress through the life cycle, they need more nutrients such as calcium and magnesium, but other nutrients such as potassium and phosphorus are not needed for some soils. These elements must be available to plants. Through various processes, it is transferred from the soil to the plant root. These processes are mass movement, diffusion and interception by the roots. Mass movement is responsible for the transport of nutrients such as calcium, magnesium and other minerals like nitrogen. The plant does not supply many other nutrients, such as P and K. Another mechanism, such as diffusion, provides phosphorus and potassium. Nutrients are transferred from their higher number to their lower amount in the mechanisms (against the concentration gradient). In soil, diffusion is very slow compared to water. Thus, for the usual plant establishment and growth, these processes are very important. Since the nutrients available to plants are responsible for these pathways.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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