Potassium Nutrition in Plants and Its Interactions with Other Nutrients in Hydroponic Culture

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http://dx.doi.org/10.5772/intechopen.71951

Abstract

Potassium is an essential major nutrient for plant growth and development. Plants absorb more K (potassium) than any other element, with the exception of N. Most plant-available forms of essential plant nutrients are ionic. Among the many plant mineral nutrients, K stands out as a cation having the strongest influence on quality attributes. Potassium ions are involved in many processes that result from ionic activity in the hydroponic nutrient solution and often provide positive contributions. Due to the presence of potassium cation ions, some elements increase in nutrient solution, whereas others decrease.

Keywords: plant nutrient, major (macro) nutrient, potassium (K), cation exchange capacity, nutrient-ion activities

1. Introduction

Light, water, and nutrients are the three essential elements for plant growth and reproduction. The nutritional factor is concerned with the content, as well as understanding the important differences between the agricultural systems and managing the plants to provide nutrients. Water-soluble inorganic chemicals are absorbed by plant roots, and these are essential plant nutrients. Plant nutrients are taken up by the plant through many biological transformations that determine when and how plants will take them.

Approximately 17 chemical elements play an important role in plant growth. Carbon, oxygen, and hydrogen are derived from air and water. They form the dry part of the plant. They are obtained by photosynthesis and are not considered “nutrient” elements. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl), and nickel (Ni) elements are obtained from the soil or hydroponic nutrient solution. Nutrient elements are essential for all plants. For some plant species, sodium, silicon, and nickel are basic nutrients and provide positive contributions to their growth, although they are not necessary for other plant species. It is imperative that the cobalt element is used for nitrogen fixation by legumes. Additional elements, such as selenium and iodine, are not necessary for plants but are necessary for humans and plant-consuming herbivores. Thus, it can be used as a nutrient for plants [1].

Potassium, together with N and P, plays an important role in plant development. It is an important macronutrient for plants having many functions such as plant nutrition, activation of numerous enzymes, and protection of electrical potential gradients in cell membranes. It is also considered as an important cation that protects the anion-cation balance. Turgor regulation and osmotic regulation in plants are greatly controlled by potassium ion. In addition, potassium is responsible for balanced transport of water to the plant [2].

Potassium is often referred to as a quality element for plant production [3] and has proven to have a crucial role in many product quality parameters. Product quality parameters such as fruit size, appearance, color, soluble solids, acidity, vitamin content, taste, and shelf life are affected positively by supplying K in sufficient quantity. These properties are influenced by photosynthesis, translocation of photosynthesis, protein synthesis, regulation of stomata, activation of enzymes, and many other processes. The tolerance of potassium to environmental stresses, such as drought, excess water, wind, high and low temperature, and the role of potassium in plant water regulation are factors that increase the productivity of trees and the quality of fruits. Plants are extremely sensitive to diseases and pests. Optimum feeding of K comes from above these troubles. In addition, other effects of potassium can be listed as follows: high fruit juice content, high C vitamin content, acceleration of ripening of fruits, and resistance to physical degradation during transport and storage [4].

Potassium has two main functions in terms of water and nutrients in plants:

1. It plays an important role in the activation of basic enzymes for the production of proteins and sugars. For this biochemical function, K is required in small quantities.
2. Potassium protects the water content in plants. Thus, as a biophysical function, it helps to maintain the turgor of the cells. Turgid cells protect the vitality of the leaf. Therefore, photosynthesis proceeds efficiently.

The relationship between the water and the nutrient content of the cell controls both the transfer of sugars produced by photosynthesis to the fruit storage organs and the transfer through the plant. The amount of potassium consumed in biophysical functions is higher than the amount spent in biochemical functions [5].

In order for plant growth to be healthy, all the essential nutrients are important at the same time. But there are huge differences in the quantities to be given to the plants. N, P, and K are **primary macronutrients** that should be given in amounts of about 50–150 lbs/acre. Ca, Mg, and S should be considered as **secondary macronutrients** required in quantities of about

10–50 lbs/acre. **Micronutrient nutrients** (Fe, Mn, Zn, Cu, B, Mo, and Cl) are generally necessary in quantities less than 1 lb/acre.

Potassium is found in a nutrient solution as almost completely free ion (K cation). Potassium ions or potassium cations play a role in **the cation exchange capacity (CEC)**. CEC prevents soluble cations from leaking out of the plant root. Potassium ions can swiftly exchange with other soluble ions [6].

Most of the plant nutrients are ionic. The K cation is a place of importance in the hydroponic nutrient solution. In many stages of the plant's nutrient uptake and afterward, the potassium cation plays an important role. The additive provided by the potassium is either direct or indirect. Indirect effects also result from the cationic property of potassium. There are several parameters that provide these effects. These parameters can be expressed as **cation exchange capacity (CEC), pH value, electrical conductivity (EC), root temperature, total ionic concentration, osmotic pressure**. In the hydroponic nutrient solution, due to the presence of K cation, the amount of some ions is suppressed, while the amount of other ions is increased. In all these cases, there is a balance effect.

The aim of this chapter is to emphasize the importance and role of potassium ion in the nutrient solution in the hydroponic system. The hydroponic system provides a controlled nutrient for the plant. Macronutrients and micronutrients required by the plant are given to the plant by controlled nutrient solution. Controlled nutrient supply increases the yield of the plant. The importance of potassium cations in transporting nutrient solutions to plants is great. Due to the cation exchange capacity, potassium ion affects many factors such as pH value, osmotic pressure and electrical conductivity in the nutrient solution given to the plant. These factors have an effective role in the productivity of the plant as well as in the nutrient uptake. The potassium ions enter the interaction and exchange process with other ionic nutrients through the cation exchange process in the hydroponic system. Therefore, this nutrient is an indispensable element of the hydroponic system. All these cases will be explained separately in the chapter.

2. Potassium nutrition in plants and its interactions with other nutrients in hydroponic culture

2.1. Hydroponic nutrient solution commonly used for plant

In hydroponic culture, nutrient solutions are the only source of plant nutrition. A solution containing all the plant nutrients must be applied in the correct balance. For the selection of fertilizers and preparation of hydroponic nutrient solutions, the following factors should be considered:

1. Concentration of harmful elements such as sodium, chloride and boron, salinity and water quality should be considered.

2. The concentration values of the necessary nutrients in the hydroponic nutrient solution should be well adjusted.
3. Nutrient balance should be provided in the nutrients that the plants receive.
4. **The pH value of the hydroponic nutrient solution** should be considered and the effect of the pH value of the hydroponic nutrient solution on the uptake of nutrients by the plants should be investigated.

In **Table 1**, it is shown common nutrient ranges in the hydroponic nutrient solutions. **Table 2** shows the recommended nutrient solutions for various plants [6].

Total salts dissolved in the hydroponic nutrient solution are considered as a measure of **electrical conductivity (EC)**. EC is a parameter used to follow the fertilization process. EC-related data do not reflect the mineral content of the nutrient solution.

The hydroponic nutrient solution is recirculated in closed hydroponic systems. Thus, the elements (sodium, chloride, fluoride, etc.) that are not absorbed in high amounts by the plants or the ions released by the plant are deposited in the hydroponic nutrient solution. In this case, the electrical conductivity (EC) cannot provide information about the content of the nutrient solution.

Element	**Ionic form absorbed by plants**	**Common range (ppm = mg/l)**
Nitrogen	Nitrate (NO_3^-), Ammonium (NH_4^+)	100–250 ppm elemental N
Phosphorus	Dihydrogen phosphate ($H_2PO_4^-$), phosphate (PO_4^{3-}), monohydrogen phosphate (HPO_4^{2-})	30–50 ppm elemental P
Potassium	Potassium (K^+)	100–300 ppm
Calcium	Calcium (Ca^{2+})	80–140 ppm
Magnesium	Magnesium (Mg^{2+})	30–70 ppm
Sulfur	Sulfate (SO_4^{2-})	50–120 ppm elemental S
Iron	Ferrous ion (Fe^{2+}), ferric ion (Fe^{3+})	1–5 ppm
Copper	Copper (Cu^{2+})	0.04–0.2 ppm
Manganese	Manganese (Mn^{2+})	0.5–1.0 ppm
Zinc	Zinc (Zn^{2+})	0.3–0.6 ppm
Molybdenum	Molybdate (MoO_4^{2-})	0.04–0.08 ppm
Boron	Boric acid (H_3BO_3), Borate ($H_2BO_3^-$)	0.2–0.5 ppm elemental B
Chloride	Chloride (Cl^-)	<75 ppm
Sodium	Sodium (Na^+)	<50 ppm TOXIC to plants

Table 1. The common nutrient range values of the ionic form of the elements absorbed by plants.

Crop	N	P	K	Ca	Mg
Concentration in mg/l (ppm)					
Tomato	190	40	310	150	45
Cucumber	200	40	280	140	40
Pepper	190	45	285	130	40
Strawberry	50	25	150	65	20
Melon	200	45	285	115	30
Roses	170	45	285	120	40

Table 2. The necessary quantities of the elements found in the nutrient solution for various plants.

The cation exchange capacity (CEC) is the cornerstone of hydroponic nutrition. The effect of potassium cation in cation exchange capacity is indisputable. The cation exchange provides the following conditions:

1. The cation exchange is the major nutrient (macronutrient) reservoir of K^+ (Monopotassium phosphate/potassium sulfate, potassium nitrate, potassium phosphate, and ammonium phosphate), Ca^{2+}, and Mg^{2+}.
2. It is necessary to keep the nitrogen (N) in the form of ammonium (NH_4^+).
3. The cation exchange helps to provide micronutrient trace metals such as Zn^{2+} and Mn^{2+} in a certain amount.
4. The cation exchange provides resistance to **the changes in pH** as well as maintaining plant nutrients.

In **Figure 1**, the cation exchange capacities on the surfaces of clay particles and organic materials with negatively charged sites holding positively charged ions are compared.

Mo and Mg are present at higher pH than most nutrients. On the other hand, trace metals such as Fe, Zn, and Mn are found at a lower pH than most nutrients. The ideal pH value for many plants is about 5.8 to 7.0. The values in this range are a balanced source for all nutrients [6].

The hydroponic nutrient solution should be checked frequently. This process provides information about the time of replacement of the nutrient solution or the time of dilution with fresh water. **The ideal pH range** for hydroponic nutrient solution is 5.8–6.3. For many plants, the optimum pH range is shown in **Figure 2**. The pH value of the micronutrients is usually below the limit value. If the pH levels fall below 5.5, the risk of micronutrient toxicity and also the impairment of calcium and magnesium accelerate. In the closed system hydroponics, the influence of the roots on the pH value of the hydroponic solution is great. This causes pH fluctuation. Sulfuric acid, phosphoric acid, and nitric acid are used to increase the acid value of the hydroponic nutrient solution. One of the most important factors affecting **the pH value of the nutrient solution** is the addition of ammonium/nitrate.

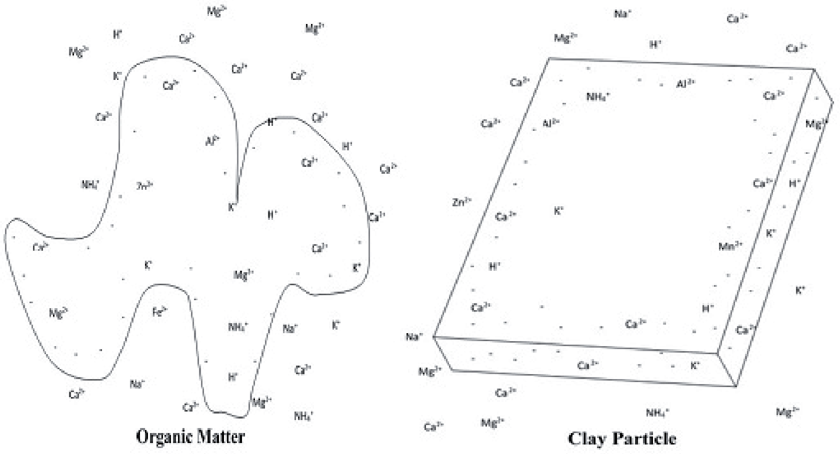

Figure 1. The appearance of the surfaces of clay particles and organic matter with negatively charged sites that hold positively charged ions.

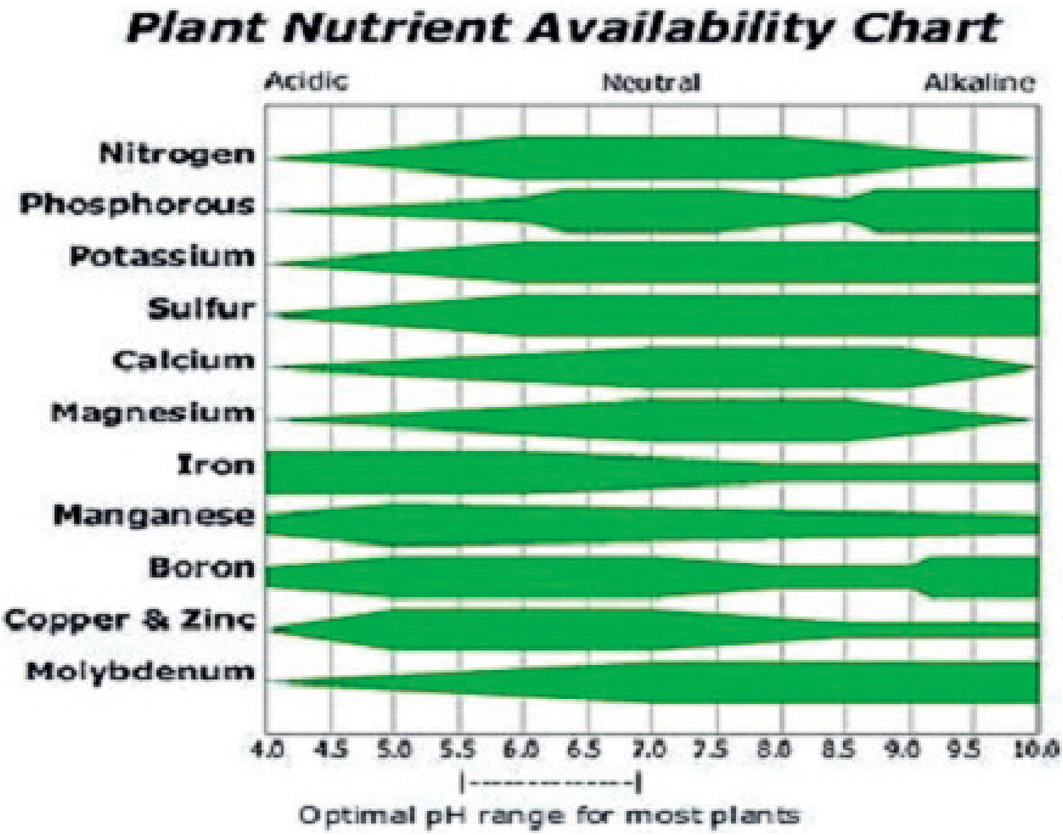

Figure 2. The ideal pH range of the elements in the hydroponic nutrient solution used for most of the crop plants.

The minerals found in raw water and the nutrients supplied by fertilization are the two main factors that bring the hydroponic nutrient solution. The quality of the raw water greatly affects the choice of fertilizers and their concentration in the hydroponic nutrient solution.

For this reason, the quality and content of the raw water should be tested before proceeding to the fertilizer formulation for fertilization. Trace elements such as boron, manganese, iron and zinc and minerals such as calcium, magnesium, and sulfur are likely to be present in the source water. Therefore, while the hydroponic nutrient solution is being prepared, the effect of these elements must also be taken into account. In addition, undesirable minerals such as sodium, chloride, or fluoride can be present in raw water. For the hydroponic nutrient solution, the presence of these minerals is undesirable. To get rid of such a situation, the following actions can be taken:

1. Raw water can be diluted by adding pure water.
2. Raw water can be desalted.
3. Ion exchange is possible [6].

The overturning and pumping of the nutrient solution can be expressed as tank exchange operations. These operations are done at a certain time/frequency. Tank exchange is one of the factors that can be controlled in hydroponic systems. There are many different ways to save time during tank exchange. One of these is the addition of a small amount of nutrient concentrate to the most consumed nutrient ions. In general, N, K, and P constitute the content of the added nutrient concentration. In a previous study, the content of daily-added nutrient concentrate was applied as 10 ppm for N and P and 15 ppm for K [7].

2.2. Interactions of potassium with other nutrients in hydroponic culture

The addition of source water and calcium nitrate causes the Ca ion to increase in some solutions. To avoid Ca addition, potassium nitrate and monopotassium phosphate are added to fertilizer materials. In addition, if the addition of potassium nitrate and monopotassium phosphate can limit the Ca value in solution, fertilization formulations are regulated by a lower Ca starting value. The nutrient tank change test provides information on how the additions of nutrients compare to tank change in normal and low calcium nutrient formulations. Researchers conducting such a test could form four different nutrient solutions. These are detailed in **Tables 3** and **4** [7].

The researchers noted the following perspectives in their work:

1. During the production, a tank change was made in the normal solution.
2. There is no tank change in the normal solution. In further treatment, daily KNO_3 and KH_2PO_4 additions were made after the tank change.
3. During the production, a tank change was made in the low calcium solution.
4. There is no tank change in low calcium solution. In further treatment, daily KNO_3 and KH_2PO_4 additions were made after the tank change [7].

Nutrient/ion	Initial normal (1)	Initial low calcium (2)	At tank change normal (3)	At tank change low calcium (4)
Nitrogen	119	127	129	129
Phosphorus	28	31	26	31
Potassium	200	233	188	231
Calcium	110	78	116	86
Magnesium	30	33	32	36
Sulfur	97	93	111	111
Sodium	72	72	86	86
Chloride	24	24	28	27
Boron	0.1	0.11	0.12	0.12
Manganese	0.04	0.07	0.04	0.05
Copper	0.08	0.08	0.07	0.08
Zinc	0.06	0.07	0.06	0.08

Table 3. Examination of tank change situation in normal and low calcium nutrient formulation.

Nutrient/ion	Normal change (1)	Low calcium change (2)	Normal no change (3)	Low calcium no change (4)
Nitrogen	61	38	41	48
Phosphorus	26	33	75	81
Potassium	68	116	244	285
Calcium	172	118	95	70
Magnesium	44	52	25	29
Sulfur	197	206	168	167
Sodium	112	115	114	111
Chloride	25	24	28	26
Boron	0.11	0.13	0.09	0.10
Manganese	<0.01	<0.01	<0.01	<0.01
Copper	0.09	0.11	0.06	0.07
Zinc	0.05	0.06	0.02	0.03

Table 4. Nutrient solutions for which there is no effect of tank replacement for normal and low calcium nutrient formulation.

In order to evaluate the data obtained for both the plant and the solution, the following results were noted:

1. No significant difference was observed between the final fresh weight yields in the four treatments.

2. There were no significant differences in tipburn ratings.
3. There was some variability in tipburn ratings among treatments. It is envisaged that less frequent tank changes can do this.
4. The starting point of the solution conditions prepared by the producers should be closely monitored.
5. The relationship between the individual conditions in the source water and other parameters should be examined.
6. The most detrimental properties of the solution are the increase in S and Na content by the end of the process. In this case, it is necessary to lower the pH. For this, a nitric acid solution should be used instead of the sulfuric acid solution. Instead of increasing the K level by the addition of KNO_3, the N level is increased by the addition of the nitric acid solution. Thus, the accumulation of S in solution is also reduced.
7. The effect of source water increases the Na level in the solution. Na level is more difficult to change. Determination of increased Na levels in time is important.
8. In this study, it was observed that some micronutrient items such as Mn were at lower levels. If the tank change intervals are to be increased, the daily additions should be selected from the most commonly used micronutrients. At regular tank change intervals, higher initial values should be applied to avoid deficiencies [7].

Potassium, which is present as a free ion in almost all nutrient solutions, has **a pH value** of 2–9 [8]. Like potassium, calcium and magnesium also have a wide pH range. However, the presence of calcium and magnesium is limited due to the presence of other ions. Therefore, if the nutrient solution contains substances above pH 7; Fe^{2+}, Mn^{2+}, PO_3^{-4}, Ca^{2+}, and Mg^{2+} precipitate to the salts. This means that the nutrients received by plants are restricted [9].

Growth, development, and production of plants are based on the **total ionic concentration** of the nutrient solution [10]. The ions of the dissolved salts in the nutrient solution have a colligative ability for nutrient solutions. This property is caused by a force called **osmotic pressure (OP)**. **The osmotic pressure** depends on the amount of dissolved substances [11]. In addition, **the dissolution potential** or **osmotic potential** terms are commonly used in nutrient solutions. Within the nutrient solution, dissolved substances have significant effects on water potential. Solvents reduce the free energy of the water by diluting the water [12]. The salt concentration determines the total amount of salts in a solution. **Electrical conductivity (EC)** is an index of salt concentration. Thus, the osmotic pressure of the nutrient solution is indirectly determined by the **electrical conductivity (EC)** parameter. EC of the nutrient solution is therefore a good indicator of the amount of ions in the root zone of plants [13].

Electrical conductivity or **osmotic pressure** is the first investigated parameter for the concentration of nutrient solution. **The regulation of pH** and **the root temperature** are also other important factors investigated for yield and quality [14]. Nutrients and water absorbers from the nutrient solution continually reinforce their electrical conductivity (EC). Thus, while the concentrations of some ions are reduced, the concentrations of some ions are also increased. This situation occurs both in closed and open hydroponic systems at the same time. For example, in a closed hydroponic system with rose production, the nutrient solution in the tank was controlled, and the results showed that the Fe concentration dropped very rapidly, while Ca^{2+}, Mg^{2+}, and Cl^- increased. In addition, there is no critical condition in the concentration levels of K^+, Ca^{2+}, and SO_4^{2-} [15]. The reuse of nutrient solutions requires regulation of EC. The reuse of nutrient solutions has been shown in various studies that have presented positive results for sustainable agricultural production systems [16]. In one of these studies, Brun et al. [17] reduced the EC by adding a water complex to the drainage; has reached the desired EC using recycling systems containing a complementary nutrient solution.

The ions which are active on EC are Ca^{2+}, Mg^{2+}, K^+, Na^+, H^+, NO^{3-}, SO_4^{2-}, Cl^-, HCO^{3-}, and OH^- ions [18]. Micronutrients such as Fe, Cu, Zn, Mn, B, Mo, and Ni do not have a significant effect on EC, since they are less likely to be taken up by plants than macronutrients [19].

The nutrient solutions contain essentially six nutrients together with Ca, Mg, and S, with preference for K, N, and P. **The ionic mutual ratio** was developed by Steiner (1961). This concept is based on **the mutual ratio of anions** such as NO_3^-, $H_2PO_4^-$, and SO_4^{2-} and **the mutual ratio of cations** such as K^+, Ca^{2+}, and Mg^{2+}. Such a ratio affects not only the total amount of each ion in solution but also the quantitative relationship that holds the ions together [10].

Soilless cultivation provides various viable and controllable possibilities to increase quality of crops and production. Parameters such as **temperature**, **pH**, **electrical conductivity**, and **oxygen content** in the nutrient solution are traceable. It is essential that these parameters are checked in a timely and accurate manner so that the advantage does not become a disadvantage [15].

When the temperature of the nutrient solution increases, **the consumption of O_2** increases. If ventilation in the root is not sufficient, **the concentration of CO_2** in the root increases [20]. In some vegetables, various investigations have been carried out on the reduction of **CO_2 concentration** by using potassium peroxide, which acts as an oxygen source [21].

Potassium is the most desirable cationic minerals for plants and constitutes 10% of the plant dry matter. Due to the reductions in KNO_3 fertilizers in the nutrient solution, the dry matter content of leaves, crowns, and roots decreased significantly. This slowed down growth and reduced the number of leaves [22]. There are a number of investigations reporting that the stomatal conductance is decreasing due to the lack of K. Accordingly, it has been reported that CO_2 fixation and phloem export are also decreasing [23]. In addition, in maize and wheat production, insufficient K levels have been observed to increase the yield of these products [24].

Various effects of K nutrition should be considered taking into account the total ion concentration (EC). At K nutrition, the relationship of K to other cations should be investigated. Among these cations, Ca, Mg, and Na in the saline irrigation water are primarily present. As a result of increasing K/Ca ratio, the storage quality is improved. In addition, flavor factors such as sugar and acid content have been increased [25].

Poor water quality can lead to excessive concentrations of NaCl in the nutrient solution. Therefore, the nutrient-ion activities may decrease and the ratios of Na^+:Ca^{2+}, Na^+:K^+, Ca^{2+}:Mg^{2+}, and Cl^-:$NO3^-$ may increase [26]. This can lead to osmotic and specific-ion damage, nutritional deficiencies, and reduced yield and quality in the plant. It was investigated by Grattan and Grieve that NaCl salinity on the tissue may have a repressive effect on the concentrations of micronutrites and macronutrients (N, P, K, Ca, Mg, and S) [26].

3. Conclusion

Potassium is of vital importance for plants nutrition. In hydroponic systems, the presence of potassium in nutrient solutions affects the processes such as growth, development, and conservation of plants in a positive way. Potassium cation has many tasks in many processes compared to other nutrients. These processes affecting the development of plants can be listed as **the cation exchange capacity (CEC)**, **the pH value**, **electrical conductivity (EC)**, **the root temperature**, **total ionic concentration**, **the dissolution potential (osmotic potential)**, **the ionic mutual ratio**, **the mutual ratio of anions**, **the mutual ratio of cations**, **oxygen content**, and **CO_2 concentration.**

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