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Potassium

Improvement of Quality in Fruits and Vegetables Through Hydroponic Nutrient Management

Edited by Md Asaduzzaman and Toshiki Asao

POTASSIUM - IMPROVEMENT OF QUALITY IN FRUITS AND VEGETABLES THROUGH HYDROPONIC NUTRIENT MANAGEMENT

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Meet the editors

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Contents

Preface

Potassium is a major nutrient in plants, which plays a vital role in cellular functions and enzymatic reactions. Growth, development, and fruit quality greatly depend on this essential element. Therefore, plants uptake potassium in higher amount than any other minerals except nitrogen. On the other hand, hydroponics is a managed culture technique where management of potassium nutrition is possible toward improvement of quality attributes in fruits and vegetables. Therefore, development of cultivation techniques following the specific management of potassium nutrition would produce enhanced quality of crops.

In this book, the role of potassium nutrition in plants, its interaction with other nutrients, and its source fertilizers are included in the first few chapters. Potassium fertilizer management and cultivation techniques of leafy and fruit vegetables are also included. Software developed for the calculation of hydroponic nutrients including potassium is also illustrated in this book for easy management of cultural solution.

Interesting researches on potassium nutrition and quality improvement in fruits and vegetables are brought together to present this book to teachers, researchers, and advanced students of plant biological science.

Publication of this book would have been impossible without the interesting research work of many researchers around the globe. Acknowledgment goes to the chapter contributors, who volunteered their valuable time to publish this book.

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Introductory Chapter: Potassium in Quality Improvement of Fruits and Vegetables

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1. Introduction

Potassium is one of the essential plant nutrients that play a crucial role in the quality improvement of fruits and vegetables. It has also a great requirement and impact on the postharvest qualities of fruits and vegetables. In this regard, hydroponic technology is a managed culture system where proper management of potassium nutrition is possible for producing quality horticultural crops. Management of chemical composition including potassium content of hydroponic culture solution and physical modification of growing environments can enhance the performance of agricultural produce. Therefore, development of cultivation methods leads to production and supplementation of specialty fruits and vegetables providing several human health benefits beyond basic nutrition.

2. Potassium as major plant nutrition

Potassium is the most abundant ion in the plant cell and regulates a range of cell functions and activates numerous enzyme reactions [1]. It is necessary for normal growth and development of plants [2] and absorbed by roots than any other mineral element except nitrogen [1, 3–5]. It has major function in the process of enzyme activation, ionic charge balance, and osmoregulation of cell [5, 6].

In terms of water and nutrient balance in plants, potassium has two major functions. It plays biochemical role in activation of enzymes for production of proteins and sugars, while it also plays biophysical function in maintaining turgor of cell and thus protecting water content in plant. A turgid cell keeps the vitality of plant leaves and efficient photosynthesis.

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Most of the researchers suggested that adequate potassium nutrition increased yields and yield attributes especially size and shape, improved qualities such as soluble solids contents, ascorbic acid concentrations, fruit color, shelf life, and also shipping quality of many horticultural crops [7–11].

3. Interaction of potassium with other nutrients

Potassium concentration affects the sodium levels in the growing medium of plants. In general, antagonistic interaction exists in between potassium and sodium uptake by plants. However, the synergistic or antagonistic effect between them depends on the amount of each element present in the soil and on the plant type [12]. Under saline condition, plants preferably uptake sodium instead of potassium. While in sodium salinity condition, plant uses more selective high-affinity system for potassium uptake in order to maintain adequate potassium nutrition. Several studies showed the antagonistic effects of potassium and sodium in corn [13], rice [14], faba bean [15], and tomato [14]. It is also reported that adverse effect of sodium on plant growth is attributed to its antagonistic relationship with calcium, potassium, and zinc in plants [13].

It is inevitable that reduced potassium supply will inhibit plant growth and yield. Therefore, investigation on minimal requirements of potassium in plants maintaining their normal growth and development is necessarily important. Recent research reported that low potassium concentration in the nutrient solution significantly decreased the fruit potassium content in netted melon [16]. In leafy vegetables and tomato, sodium and magnesium content found to be increased significantly when potassium content was restricted to the culture solution [17].

Research results also showed that decrease in potassium levels increase the concentration of sodium and magnesium in tomato fruits [18, 19]. Sodium concentration in melon fruit increased with the decrease of potassium concentration in the nutrient solution and its concentration increase to 56% compared to standard concentration when plants were cultured without potassium fertilizer from anthesis to harvest [16].

4. Hydroponic nutrient management for improving quality of fruits and vegetables

Hydroponic nutrient solution contains mainly inorganic soluble salts of essential elements for higher plants. Each essential element has a clear physiological role, and its absence prevents the plant from normal growth and development [20]. Mineral composition in nutrient solution determines different chemical properties such as pH, electrical conductivity, and osmotic potential that affect uptake by plants. In general, hydroponic nutrient solution contains sufficient amount of essential nutrient for luxurious uptake by plant roots. If it is applied continuously, plants can uptake essential ions at very low concentrations. Therefore, researchers reported that higher concentrations of mineral nutrients are not used by plants or their uptake does not impact the higher production. It has been shown that the concentration of nutrient solution can be reduced by 50% without any adverse effect on biomass and quality in gerbera [21] and geranium [22].

In another study, no adverse effect on growth, fruit yield, and fruit quality in tomato was reported when there is reduction of macronutrient concentrations to 50% of the control level [23]. High levels of potassium in the nutrient solution increased fruit dry matter, total soluble solid content, and lycopene concentration of tomato [24]. Recent studies showed that reduced KNO_3 concentration in standard hydroponic nutrient solution produced melon fruits with lower potassium content [16].

5. Production of specialty vegetables through hydroponic nutrient management

Potassium plays an important role in our body through several vital electrolytic activities. Chronic kidney disease (CKD) patients can't excrete unnecessary potassium through their impaired kidneys and thus get accumulated in the blood. This abnormally elevated level of potassium in the blood causing hyperkalemia disease to them. Hyperkalemic or dialysis patients are suggested to avoid potassium-rich food, but our daily diets including fruits and vegetables are rich in potassium. Therefore, production of low potassium content fruits and vegetables would benefit this type of people greatly.

In general, the greenhouse cultured raw melon has higher potassium content of 340 mg/100 g fresh weight [25]. Significant decreases in potassium content in melon fruits would improve the diet of dialysis patients. Therefore, quantitative management of hydroponic culture solution yielded melon fruits having sufficiently low potassium content (**Figure 1**) [16]. A simple management of

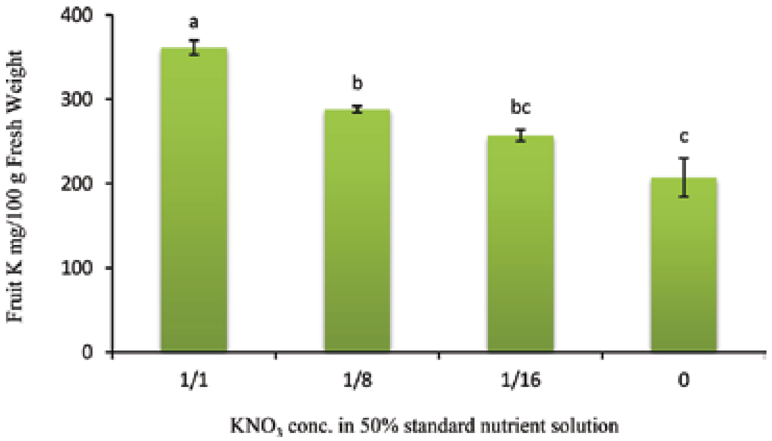

Figure 1. Reduced potassium nitrates levels decrease the fruit potassium content of netted melon grown in hydroponics [16].

culture solution was used for melon by reducing the potassium at lowest possible level. Therefore, melon plants were grown in nutrient solution with reduced KNO_3 concentrations from anthesis till harvest to investigate its impact on the fruit potassium content while maintaining normal growth, yield, and other fruit qualities. On the other hand, sodium concentration in melon fruits followed the reverse trend of potassium concentration. Its concentration increased significantly in all the reduced potassium levels of KNO_3 supplied during anthesis to harvest. It was found that melon plants grown in nutrient solution without potassium nitrate during anthesis to harvest produced fruits with an increased sodium concentration of about 56% (**Figure 2**).

Strawberry is the most popular fruit in the world. This sweet-sour taste fruit rich in potassium attracts all aged people. However, elderly people suffering from chronic kidney disease are restricted to eat this fruit. In general, greenhouse-cultured fresh strawberries have a high potassium content of 170 mg/100 g FW of fruit [25]. In this regard, reducing this potassium level in strawberry fruit would remove the dietary restriction to CKD patients. Therefore, our research team also tried to produce low-potassium strawberries through the management of a KNO_3 fertilizer in nutrient solution from anthesis to the harvest period. In strawberry plants that were grown in 1/32 level of KNO_3 of the standard nutrient solution, fruit potassium was decreased about 23.5% compared to the typical level of potassium in strawberry fruit of 170 mg/100 g FW [25, 26].

Similar to melon and strawberry, tomato is a potassium-rich fruit vegetable. If low-potassium tomato fruit can be produced, it can improve the dietary options of dialysis patients and their quality of life. A method of producing low potassium content tomato fruit was investigated [27].

Hydroponic culture methods for spinach have been investigated with lower levels of potassium in the culture solution [28]. Spinach plants were grown hydroponically either with reduced potassium application throughout the growth period or without potassium applications during the last half of the growth period. No significant differences in fresh weight that were observed in plants cultured with either of the solution. However, the potassium content in plants was reduced as much as 32% by reduced potassium application throughout growth period and

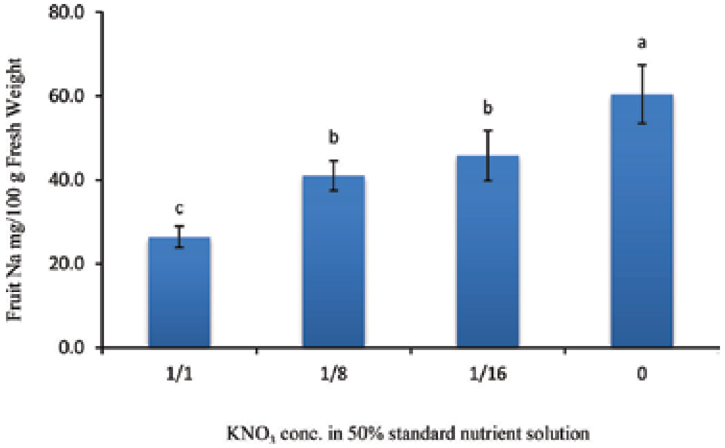

Figure 2. Reduced potassium nitrates levels increases the fruit sodium content of netted melon grown in hydroponics (data not published).

79% by without potassium application during the latter half of growth period compared to control. These results suggest that it is possible to produce low-potassium spinach maintaining the normal plant growth. Other minerals like sodium and magnesium content increased with the decrease of potassium content, showing antagonistic role in osmotic pressure balance.

Lettuce is a popular potassium-rich vegetable usually eaten raw in the salad. CKD patients with hyperkalemia cannot intake large quantities of raw vegetables like lettuce, tomato, strawberry, etc. Therefore, producing low potassium vegetables would be highly appreciable from the viewpoint of dietary restriction. In this case, hydroponic culture systems have wide acceptability as it allows greater control over the root zone environment than soil culture, which makes nutrient management easy based on the plant requirements. Recently, low-potassium-content lettuce has been established by potassium fertilizer management [27]. Hydroponic culture systems have become widely used because they allow greater control over the root zone environment than soil culture, which makes nutrient management easy based on the plant requirements.

6. Conclusion

Potassium is the crucial macronutrient and main electrolytes in plants. Its requirement is higher than other mineral nutrients except for nitrogen, but some crops at their specific stages demand more potassium than nitrogen. Therefore, adequate potassium fertilization is necessary for enhanced and improved yield and qualities of agricultural produce. This monovalent cation interacts both antagonistically and synergistically with other nutrients. In hydroponic nutrient solution, it shows clear antagonism with sodium at its reduced levels. In this regard, management of potassium nutrient based on crop growth stage and following other culture techniques can produce specialty horticultural crops providing human health benefits. For example, low potassium content melon, strawberry, tomato, lettuce, and other leafy vegetables can improve quality of life (QOL) of CKD patients.

This book aims to enumerate available resources on potassium, its importance to plants yield and quality, management in the hydroponic culture solution, and cultivation techniques of production specialty horticultural crops. The content also discusses news ways of managing and developing sustainable production techniques and software for quality horticultural crops through potassium nutrition.

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Chapter 2

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

Betül Çalişkan and Ali Cengiz Çalişkan

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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.

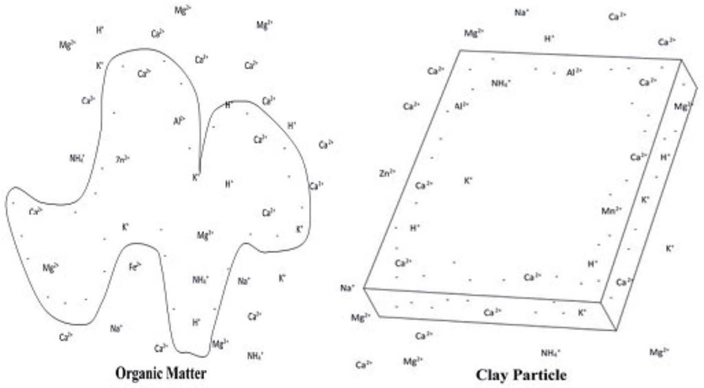

Figure 1. The appearance of the surfaces of clay particles and organic matter with negatively charged sites that hold positively charged ions.

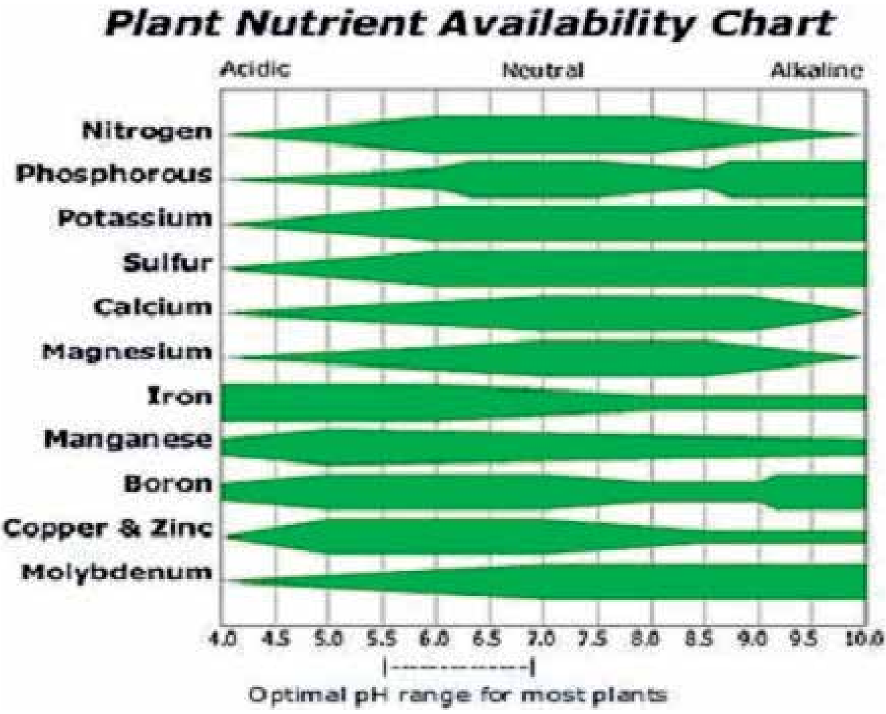

Figure 2. The ideal pH range of the elements in the hydroponic nutrient solution used for most of the crop plants.

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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Potassium Nutrition in Fruits and Vegetables and Food Safety through Hydroponic System

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Additional information is available at the end of the chapter

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Abstract

Although it is not an element with structural function in plants, potassium (K) is demanded in considerable quantities by plants due to multifunctional role in plant physiology and metabolism. Nevertheless, the interface of plant mineral nutrition and food safety evidences needs for a better understanding of functional mechanisms of this nutrient in plants, taking into account its management in hydroponic cultivation and food production with nutritional quality. Thus, the nutritional content of K in vegetables is indicative of post-harvest and nutritional quality. This fact is important considering that modern life has induced increased consumption of processed foods whose preparation implies reduction of K levels and increase of Na levels, with the consequent low K intake and appearance of diseases related to insufficient intake. Therefore, the present chapter aimed to address main nutritional, physiological, and biochemical aspects of K in a context of hydroponic plant production and importance of potassium nutrition to human health.

Keywords: K, plant nutrition, transport of K, food, metabolism

1. Introduction

The term “potash” describes a variety of extracted and manufactured salts containing chemical element potassium (K) in water-soluble form. It is one of three primary nutrients for plants, along with nitrogen and phosphorus, with about 90% potash being used in the production of fertilizers [1]. The K, abbreviation of word neo-latina *kalium* (derived from “alkali,” latinized form of Arabic *al-qali* which means calcined ash), was isolated like an element by Humphry

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Davy in 1807, but its compounds were already used in processes known from ancient times [2]. From the chemical point of view, K belongs to alkali metal family, being a univalent ion ray cation of 0.331 nm and hydration energy of 314 mols^{-1} [3].

The K is an essential macronutrient and one of the most important cations in higher plants, constituting about 2–10% of the mass of the dry matter [4]. The K is essential for enzyme activation, protein synthesis, and photosynthesis, as well as modulating osmotic regulation during cell expansion, stomatal movements and tropism [5], and transport of photoassimilates of fabrics sources for fabrics drains [3]. The cytoplasmic concentration of K in plant cells is estimated to be around 100 mM (40–200 mM). This concentration of K appears to be relatively stable, with an optimal concentration of K for enzymatic activity [6]. On the other hand, the concentration of K in the soil is low, being in micromolar range of 0.1–1 mM [7].

The absorption of K is performed by means of three groups of membrane proteins, the permeases (KT/HAK/KUP), transporters (Trk/HKT), and by proteins of cation-type antiporter (CPA) [8]. Electrophysiological studies have shown that under K millimolar concentrations, K absorption occurs passively through ion channels and actively through H^{+-}cotransporters when the K concentration is in the micromolar range [9, 10]. When K concentration in the soil solution is below 0.2 mM, high-affinity absorption mechanisms are activated; on the other hand, when K concentrations are above 0.3 mM, mechanisms of low-affinity absorption are activated [9, 11, 12].

In plants, K is characterized by great mobility, being easily transported to aerial part or even redistributed among various organs of plants. Due to considerable number of functions performed by K in plants, this macronutrient plays an important role in plant growth and development, as well as food quality.

Adequate potassium nutrition is associated with increased fruit production, fruit size, soluble solids increase and ascorbic acid concentration, fruit color improvement, fruit shelf life, and supermarket shelf life [13–16]. Additionally, K is involved in post-harvest quality of vegetables and fruits; it is considered a nutrient associated with quality of products of plant origin due to its important effects on post-harvest attributes such as color, size, acidity, resistance to transportation, handling, storage, nutritional value, and industrial qualities [17, 18].

One of strategies of high-quality food production is the adoption of hydroponic system of cultivation, in which the control of plant nutrition (i.e., concentration of nutrients, pH, and electrical conductivity of nutrient solution) and growing environment (i.e., temperature, luminosity, and humidity) are more effective in obtaining high-quality vegetables compared to field cultivation. Hydroponic vegetable production has increased significantly in recent years worldwide, allowing more efficient use of water and fertilizers, as well as better control of climatic and phytosanitary factors. In addition, hydroponic production increases the quality and productivity of vegetables, resulting in competitiveness and profitability [19].

In fact, there is a close relationship between plant nutrition and food safety, considering potassium nutrition interface of vegetables and human health, since one of the conditions for safe food is the production and availability of foods with nutritional quality [20]. Thus, good management of vegetable nutrition can contribute not only to gains in productivity and post-harvest quality but also to people's quality of life through the ingestion of healthy foods rich in mineral nutrients.

Coincidently, one of the most important mineral nutrients for human health is K; from physiological point of view it plays an important role in the conduction of electrical impulses by cells of nervous system, muscle contraction, and vascular functioning [21]. There are several food sources that can satisfy human needs of K, such as vegetables of its accessibility, low cost to consumer, and easy nutritional management. However, the production of vegetables in quantity and quality in hydroponic system is closely linked to nutritional management, especially of potassium nutrition, given the great importance of this nutrient in physiology and post-harvest quality of plants of food interest. The present chapter aimed to address the main aspects of potassium nutrition of vegetables and fruits, emphasizing the importance of interface plant nutrition and food safety in hydroponic farming system.

2. Source of potassium fertilizers

In hydroponic cultivation, the supply of K is carried out from fertilizers containing this element, which have considerable amounts of other nutrients as accompanying ions (**Table 1**). Thus, the choice of source depends on factors such as availability, commercial value, the requirement of culture by accompanying ion, and saline index. However, it is important that more than one source is available to facilitate the equilibrium of final concentration of K in culture solution, which depends on the requirement of each culture.

Fertilizer	Formula	Nutrient	Concentration (%)	Solubility (g L^{-1} at 20°C)
Potassium nitrate	KNO_3	K	38	316
		$N\text{-}NO_3^-$	13	
Monopotassium phosphate	KH_2PO_4	K	28	226
		P	23	
Potassium sulfate	K_2SO_4	K	45	111
		S	18	
Potassium chloride	KCl	K	60	330
		Cl	48	

Source: [19]

Table 1. Fertilizers containing potassium that is commonly used in the preparation of nutrient solutions.

3. Potassium nutrition in vegetables

The vegetables are very demanding in K and some species such as tomatoes require it in greater quantity than nitrogen (N) [22]. The factors that contribute to high requirement, in general, are a short cycle and short absorption period associated with high demand for nutrient. An important tool to assist technicians and producers with regard to nutrient quantity and application times is the study of gait of nutrient accumulation [23], which changes according to species. For example, while in tomato the demand for K increases over time, especially in fruiting phase [22], in lettuce plants, the rate of absorption of K decreases during the days of cultivation [24]. Another factor that must be taken into account when choosing the amount of nutrients to provide is where the recommendation information was obtained and should be representative of place where the recommendation will be used. In this context, the manual of recommendation for fertilization of vegetables, [25] clarifies the recommendations that should be followed in the absence of local information.

In relation to evaluation of nutritional status of crops, the main ways to do this is through visual analysis of deficiency or excess symptoms and nutrient content of plant tissue (leaf analysis). The visual analysis has the advantage of low cost, for dispensing laboratory analysis. However, when the plant expresses the symptoms of deficiency in the histological plane, much of productivity is compromised, which is an undesirable situation for producers. Leaf analysis has the advantage of detecting symptoms of deficiency or excess of nutrient that are not being demonstrated in the histological plane, by comparison with pre-established reference values.

The same care described about the use of recommendations should also be taken in relation to the use of reference values. For example, Trani et al. [26] indicate that for sugar beet, the critical K content ranges from 20 to 40 g kg^{-1} for field crops. However, if there is a change in cultivation system with an increase in green fertilization [27] and hydroponic cultivation [28], the critical levels of K increased to 70 and 84 g kg^{-1}, respectively.

A relevant nutritional aspect related to plant nutrition is a relationship between nutrients, because of its dependence on the chemical nature of nutrient. It also can affect absorption through root system, thus absorption rate of one ion can be affected by another, which are competing for the same membrane carrier [29]. This fact will depend on its concentration on nutrient solution, the permeability of nutrient to membrane, and its mechanism of absorption [30]. Thus, increasing the concentration of particular nutrient in nutrient solution may interfere with the plant's absorption of other nutrients. In this context, the important relationship between K, Ca, and Mg is framed and these three nutrients are found in expressive concentrations in plant tissues.

The K competes with Ca and Mg for the same membrane carrier and increase in K concentration in nutrient solution implies reduction in Mg uptake. Similarly, increasing K concentration may reduce Ca uptake, because K is preferentially transported in plant compared to Ca [31]. The Ca competes with Mg, which makes the absorption reduced and this is due to the high energy of hydration and the larger size of ionic ray of Mg^{2+} ion, when compared with the Ca^{2+} ion. Due to competition, it is possible to observe Mg deficiency in plants, which means high doses of potassium and calcium fertilizers [3]. According to Forster and Mengel [32], the reduced concentration of K in nutrient solution allowed a higher absorption of Ca and Mg; there is no competition between the nutrients for absorption site. Due to these factors, it is not a concern to describe the concentrations of K used in nutrient solutions as well as adequate levels of K in leaf tissues; the objective of this section on potassium nutrition is to demonstrate some examples of the role that K has on the plants, ranging from the seed to the final quality of the product.

It is possible to manage potassium nutrition in hydroponic systems considering the cultivation of plants with different objectives, since the maintenance of high K/Na ratio in the cytosol is of vital importance for the functioning of plant cells [33, 34], for example, the production of K-poor edible plants for groups of people with chronic kidney disease who have difficulty excreting K. In an experiment with strawberry plants grown under a hydroponic system and decreasing concentrations of KNO_3 in the phases comprised between anthesis and fruit formation, [35] obtained strawberry fruits with low K contents when the concentration of K in the nutrient solution corresponded to 1/32 of the control treatment. For this concentration of K, there was no reduction in yield and fruit quality. However, in a study with melon plants under hydroponic conditions [36] did not obtain similar results, since the melon plants absorbed and stored considerable amounts of K before the application of the restriction treatments of K in the nutrient solution. In this study, a significant redistribution of K of the vegetative structures was observed for the melon fruits.

In another study, there was the equivalent substitution of K for Na in sugar beet plants cultivated in a hydroponic system [37]. In this study, the equivalent substitution of K for Na did not promote growth reduction, but only significantly reduced the calcium contents in the shoot and root. Plants that support the substitution of K for Na without damage to the growth and ionic homeostasis are called natrophilic, being included in this classification sugar beet [37].

The management of K in hydroponic system can improve the growth of plants cultivated under conditions of saline stress. In a study with five tomato genotypes, [38] observed that 2 mM of K supplementation mitigated the effect of saline stress by promoting greater leaf, root, and fruit yield. However, it should be considered that the response to K addition was genotypic, since the Pearson cultivar presented the best response to the addition of K.

In order to evaluate induced changes in the proteomic level by the substitution of K for Na or even K deficiency in sugar beet plants, [39] observed that a wide range of physiological processes were impaired by K deficiency, such as light reactions of photosynthesis, CO_2 assimilation, glycolysis, and tricarboxylic acid cycle. Stimulation to the photosynthetic process was observed when there was K deficiency; however, due to the presence of Na, the cellular respiration process was affected. This study evidenced that Na is able to repair some damage due to K deficiency, but it did not replace K as an essential element to the growth of plants.

4. Potassium nutrition and quality of seeds and seedlings

The attention to adequate potassium nutrition must occur from the acquisition of seeds because nutritional status of mother plant affects not only the final yield of crop but also the quality of seeds produced. For example, Marrush et al. [40] found that K deficiency benefits a high incidence of premature germination, in other words, viviparity in bell pepper plants (*Capsicum annum* L. cv. "California wonder").

Consequently, the deficiency of K in mother plant, during the phenological stage of seed formation, may decrease the germination rate of harvested seeds [41]. However, the seeds of plants well-nourished with K may present the germination rate due to the accompanying ion of the source of K used, because of a negative correlation between germination percentage and concentration of Cl in sweet pepper seeds [42].

In relation to the production of *Brassica oleracea* seedlings, Zhang et al. [43] have demonstrated that although it depends on a relationship with other nutrients, the enrichment of substrate with K provides more vigorous seedlings. However, there is little research to verify if investment in seedling production is offset by the final productivity of plant in the field.

5. Potassium nutrition and its relationship with abiotic and biotic stresses

Among the factors that affect global food security are availability and quality of water resources [44]. Due to low availability of drinking water, the development of techniques that allow the lowest consumption of water or use of salt water in hydroponics is important to allow advancement in this mode of cultivation [45].

In this sense, an increase of K application in sweet potato plants irrigated with 50% of the field capacity was detrimental to the development of plants [46]. In relation to the use of salt water, one of negative consequences in hydroponics is a decrease in the accumulation of K [47]. However, it has been demonstrated in literature that, in tomato cultivars, the increase of K concentration in nutrient solution can be used to minimize salinity-induced oxidative stress, increasing the photosynthetic rate of plants and making them less sensitive to salinity [48]. Besides that, Ramadan and Shalaby 2016 [49] indicated that the foliar application of K resulted in an increased growth and yield of eggplants grown under conditions of salt stress.

A common situation in less-tech hydroponic crops is a lack of temperature control in production environment, because in these environments the temperature is not controlled, temperature variations are usually observed, which has harmful effects on plants. Thus, in an extensive compilation of data, Oosterhuis et al. [50] described that high K concentration in cells can improve cold stress tolerance by reducing the osmotic potential of cells and decreasing the freezing point of sap, preventing cell dehydration. On the other hand, considering that hydroponic crop plants experience high temperatures, but without water restriction, Römheld and Kirkby [51] indicate that an adequate nutrition results of K in an increase of plant's capacity to eliminate the reactive oxygen species. It is produced during the thermal stress and improving the efficiency of water use, these main factors are necessary to make plants less sensitive to heat.

In hydroponic crops, nitrogen is mainly supplied as nitrate (NO^{3-}). For leafy vegetables, the accumulation of NO^{3-} is a concern for humans, especially for children, it can be harmful to health, depending on the amount consumed in the diet [52]. Thus, the inclusion of ammoniacal N can promote a significant increase in productivity and contribute to growing demand for safer foods. However, several factors may alter the availability of ammonium (NH_4^+) to plants and increase their rate of absorption by plants, which may lead to phytotoxicity [53].

Potassium nutrition is efficient in minimizing the phytotoxic effects of excess NH_4^+, since K and NH_4^+ are very similar in relation to valence and ionic radius, in addition to being absorbed by the same carrier. Thus, increased K concentration may inhibit or even decrease NH_4^+ uptake and thereby mitigate the phytotoxic effects of excess NH_4^+ [54]. In addition, Hernandez-Gomez et al. [55] verified that the cultivation of peppers with high concentrations of NH_4^+ was possible to maintain plant productivity, increasing the K concentration of nutrient solution, which resulted in adequate K contents in the plant tissue. Also, in this study, the water relations, the photosynthetic rate, and the stomatal conductance were not affected, compared to plants cultivated with a high concentration of NH_4^+ and a low concentration of K.

K plays a very important role in the mitigation of biotic stresses to which plants are susceptible, since it participates in the synthesis of high-molecular-weight compounds such as proteins, starch, and cellulose, reducing the accumulation of soluble sugars, organic acids, and amides, of which pathogens are fed [3]. In this context, Perrenoud [56] gathered a series of studies where the incidence of pests and diseases was reduced as a function of nutrition with K and diverse cultures. However, there are important relationships of K with other nutrients, and an adequate K/N ratio in plant tissue may be responsible for increased productivity, lower incidence of diseases, and increased quality of product harvested.

For example, Adams and Massey [57], in order to maximize productivity, fruit quality, and greater resistance to diseases in tomato, suggest a K/N ratio of 1.2/1 in vegetative stage and 2.5/1 in reproductive stage. Another important factor to consider is the nutrient concentrations, which must be adjusted, depending on several factors. This way, Nam et al. [58] demonstrated a concentration of K in strawberry; this element was responsible for a higher productivity, but was not the same that bring results about lower incidence of diseases, which indicates that in conditions of high productivity, the quality of food can be affected.

6. Potassium and post-harvest nutrition of vegetables

Potassium is present in plant cells in cationic form K and plays an important role in the physiological activity of plants. In addition to metabolic functions of K in photosynthetic metabolism, enzyme activation, protein synthesis, osmotic regulation, and stomatal movement [59], K has a close relationship with post-harvest quality of vegetables, because post-harvest parameters such as fruit size, soluble solids, lycopene, and vitamin C concentration are influenced by this nutrient.

There is a set of experimental evidences that show a relationship between potassium nutrition and post-harvest quality of vegetables, since several studies report the effect of potassium nutrition on the post-harvest of fruits and leafy vegetables. In tomato fruits, the potassium nutrition provided under fertirrigation increased the concentration of lycopene in genotypes with contrasting production of lycopene [60]. This pigment or bioactive compound is associated with important antioxidant functions by acting on the detoxification of free radicals, reducing the appearance of cancers such as prostate [61, 62] and avoiding the onset of heart disease [63].

In another study about potassium fertilization in tomato plants, there is a linear increase in the concentration of lycopene with potassium fertilization [64]. This close relationship between potassium fertilization and concentration of lycopene in tomatoes seems to be related to enzymatic activation function exerted by K; more than one enzyme of metabolism of lycopene synthesis has the K activation cofactor, for example, phytoene desaturase or phytoene synthase, an enzyme that catalyzes the reaction of phytoene synthase from geranylgeranyl diphosphate, which is the first step in the route of carotenoid synthesis [65].

Another important antioxidant, vitamin C or acid ascorbic, is positively influenced by potassium nutrition, since several studies report a higher concentration of vitamin C as a function of potassium nutrition, as observed in pepper [66] and chili. K is responsible for the uniform ripening and the increase of acidity of fruit that is an important characteristic for quality and flavor of fruit [67].

With the advancement of ripening process, tomato fruits present changes in their characteristics as flavor and color. The taste of tomato is attributed to the content of soluble solids [68], acids, and volatile compounds [69]. The total soluble solids present greater accumulation in the final phase of maturation also is constituted of 65% of sugars (sucrose and fructose).

Soluble solids present in fruits such as watermelon, melon, tomato, and strawberry include important compounds responsible for taste and consequent acceptance by consumers, and the most important are sugars and organic acids. In general, there is a close relationship between potassium nutrition and soluble solids content as evidenced in several studies such as tomato fruit [60, 70]. It should be considered that the production of soluble solids is a genetic characteristic, but it is influenced by ambient temperature, irrigation, and fertilization [71].

7. Potassium and plant physiology

Potassium is present in plant cells in cationic form K and plays an important role in the physiological activity of plants. In general, K has a close functional relationship with photosynthetic metabolism, enzyme activation, protein synthesis, osmotic regulation, ionic homeostasis, and regulation of stomatal movement [59].

The modulation of photosynthetic activity by K occurs at several levels; however, its role in ionic equilibrium shows to be a major one. For example, K is a dominant ion that promotes the balance of positive charges due to the light-stimulated H^+ flux through the thylakoid membranes. In addition, it contributes to the generation of transmembrane pH gradient necessary for the synthesis of ATP by photophosphorylation. To maintain high pH (low H^+) in the stroma during light, additional K influx from the cytosol is required, in a process mediated by an H^+/K^+ antiporter carrier [3]. However, the osmotic regulation of guard cells by K is a relevant factor in the control of gas exchange and water losses in plants, due to smaller or larger stomatal opening [72].

The K, as well as other univalent cations, activates enzymes by inducing conformational changes in their structures, making them biologically active and these changes are possible due to electrostatic bonding of K to enzyme [73]. Thus, K contributes to the occurrence of group of biochemical reactions of great physiological importance, such as the activation of carbohydrate metabolism enzyme in particular of pyruvate kinase (EC 2.7.1.40) and phosphofructokinase (EC 2.7.1.11), which catalyze the transference of phosphoric groups to pyruvate and D-fructose 6-phosphate, respectively [74].

Regarding protein synthesis, K is required at higher concentrations compared to its enzymatic activation function, which, for this function, the required K concentration is about 50 mM [3]. Due to osmotic properties, K plays an important role in the opening of stomata during the first hours of the day. This physiological phenomenon consists of influx of K in the guinea pigs, where the concentration of K increases from 100 to 400 mM or 800 mM, but decreasing throughout the day [72, 75].

K is also involved in the loading of sugars into phloem in a process coordinated by AKT3/3-like channels located on the brassicaea phloem *Arabidopsis thaliana* [76]. This process of loading sugars into phloem has great physiological importance because it allows the translocation of sugars from the source tissues to drainage tissues to supply the needs of growing organ such as roots system, fruits, and flowers [72].

Under conditions of adequate potassium availability, K uptake occurs through low-affinity transporters [77], with K translocation to plant tissues and redistribution to drain tissues. At the same time, photoassimilates are produced by the photosynthetic process and transport the same to drainage organs, with the consequent development and growth of plants (**Figure 1**). On the other hand, K deficiency triggers a set of changes in plants, which initially manifests in gene and molecular plane and then in physiological and morphological plane, culminating in the reduction of plant growth.

With low concentration of K in the plant growth substrate, carbohydrate metabolism disorders occur due to K being in low cell concentration to activate key enzymes of carbohydrate metabolism. With this, there is accumulation and inhibition of transport of photoassimilates from the source organs to draining organs, with the reduction of photosynthetic activity. In another way, K deficiency leads to changes in gas exchange, with reduction of stomatal conductance, reduction of CO_2 diffusion, and photosynthesis.

As a consequence, the consumption of NADPH-reducing power by Calvin cycle decreases, with the superduction of electron transport chain and the generation of free radicals, culminating in photooxidation, followed by chlorosis and foliar necrosis (**Figure 1**). In the attempt to reestablish ionic homeostasis, plants promote redistribution of accumulated K; however, due to classical relationship between K, Ca, and Mg, these latter two macronutrients are absorbed in greater intensity, compared to K, under conditions of K deficiency (**Figure 1**).

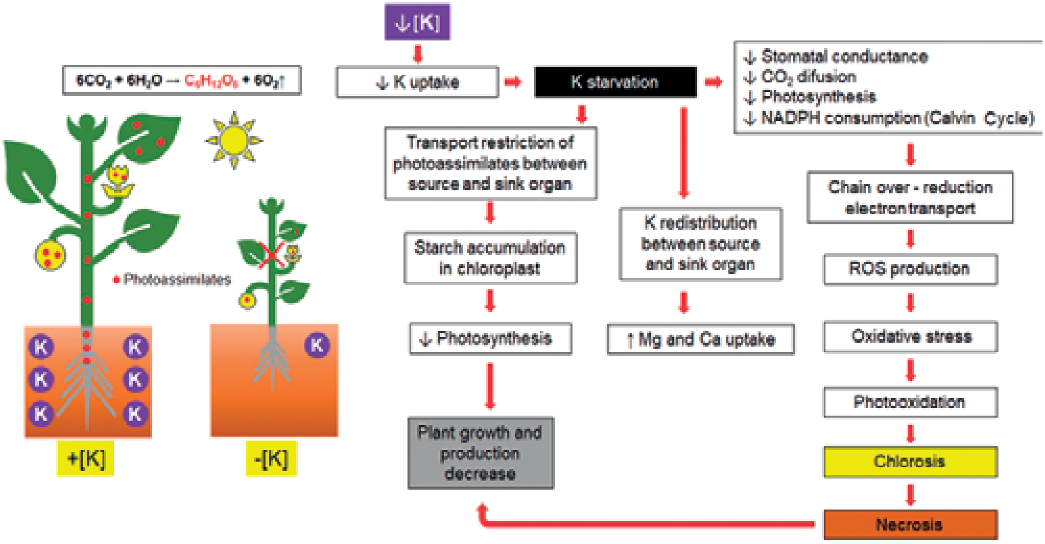

Figure 1. Physiological response of plants to normal and deficient potassium supply.

Due to importance of K in plant physiology and nutrition in relevant literature, several studies report negative effect of K omission on growth (i.e., plant height, leaf area, shoot dry mass accumulation, and root) and mineral metabolism of plants (i.e., nutritional balance of plants), like was observed in beet [78], cabbage [79], lettuce [80], and eggplant [81].

8. Potassium deficiency and toxicity symptoms in vegetables

As in other nutrients, K deficiency changes at different levels. The deleterious effects of deficiency begin in the dynamics of metabolism in biochemical plane, evolving at molecular, subcellular, and cellular levels, until reaching the tissues [23]. The visual perception of deficiency occurs when it reaches the level of tissue, that is to say that when verifying visual damages, a series of events deleterious to the development of plant have already occurred.

The first structures to experience potassium deficiency are the roots where there is a drastic reduction of nitrate levels, intermediates of glycolytic route (pyruvate), amino acids like malate and oxoglutarate, negatively charged amino acids such as glutamate and aspartate, increase in levels of soluble carbohydrates (sucrose, glucose, and fructose), and many amino acids with high C/N and/or positively charged amino acids such as glutamine, glycine, and arginine [81]. In addition, there is less transport of photoassimilates from the aerial part to roots, thus reducing root growth. In the strawberry, potassium deficiency increases the amount of root exudates favoring the infection and colonization of *Fusarium oxysporum* [82].

In the leaves, in the beginning of K deficiency, the content of this nutrient in the cytosol remains constant, although there is a decrease in the K content of vacuoles, probably because this reserve structure of K supplies the demand of cytosol. As deficiency persists and plant demand increases, cytosolic K reduction also occurs [83]. With this reduction, some enzymes such as pyruvate kinase are negatively affected, inhibiting glycolysis and causing a series of metabolic disorders following the tricarboxylic acid cycle [81].

There is an increase in the content of soluble carbohydrates in leaves due to reduction of their conversion to starch and reduction in the content of α-ketoglutarate derivatives [84–86]. Due to the decrease in the synthesis of compounds of higher-molecular weight, the leaves become more susceptible to attack by pests and diseases.

However, Carmona et al. [87] observed in cucumber plants the initial visual symptoms of K in the intermediate leaves (**Figure 2**). These authors suggest that the appearance of symptoms in intermediate leaves occurs as a function of time when the omission of K was applied (beginning of the fruiting), because the fruits in formation are strong drains of this nutrient, being the adjacent leaves to satisfy the demand of K of the fruits. In plants with undetermined growth, such as bean pod case (**Figure 3**) and in reproductive stages, potassium deficiency can also be observed in intermediate leaves, since leaves close to reproductive structures tend to supply K reproductive organs.

K is very mobile in plant being visible deficiency symptoms in the more mature leaves. It begins with a marginal chlorosis, which can also occur at leaf tips, followed by foliar limb necrosis and even necrotic part breakage (**Figure 4**) [88]. Carmona et al. [87] observed in cucumber plants the initial visual symptoms of K in the intermediate leaves (**Figure 2**). These authors suggest that the appearance of the symptoms in intermediate leaves occurs as a function of time when the omission of K was applied (beginning of the fruiting), because the fruits in formation are strong drains of this nutrient, being the adjacent leaves to satisfy a demand of K in fruits. In plants with undetermined growth, such as the bean pod case (**Figure 3**) and in reproductive stages, potassium deficiency can also be observed in intermediate leaves, since leaves close to reproductive structures tend to supply K reproductive organs.

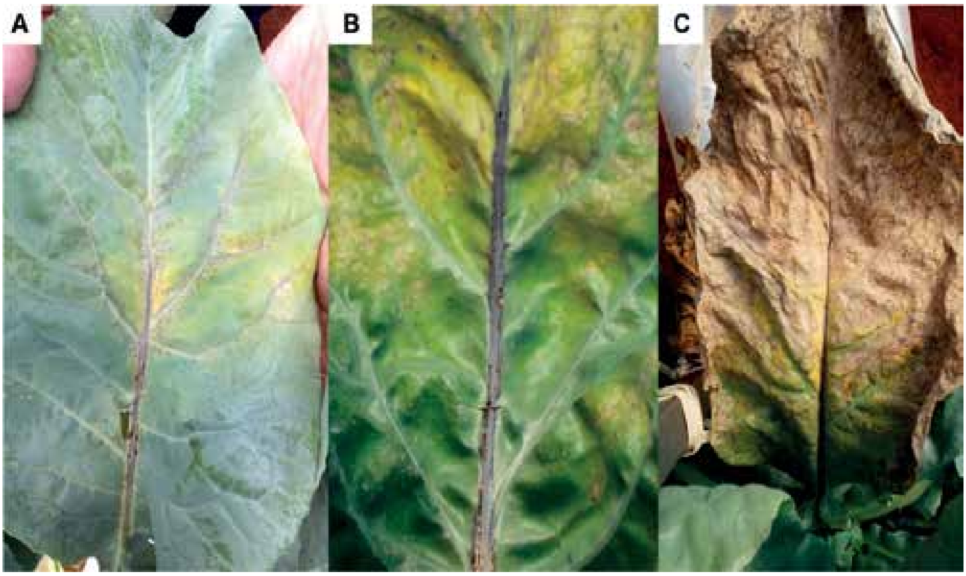

Figure 2. Initial chlorosis (A and B) and advance to marginal necrosis (C) in intermediary leaves of "Nikkey" cucumber as an effect of the omission of K in the nutrient solution. Source: [87].

The deficiency of K leads to lower protein synthesis and accumulation of soluble nitrogen compounds such as putrescine, toxic to plants [88]. The central area of leaves may be dark green in color, similar to phosphorus deficiency and a thickening of nervure in leaves (**Figure 4**) [88].

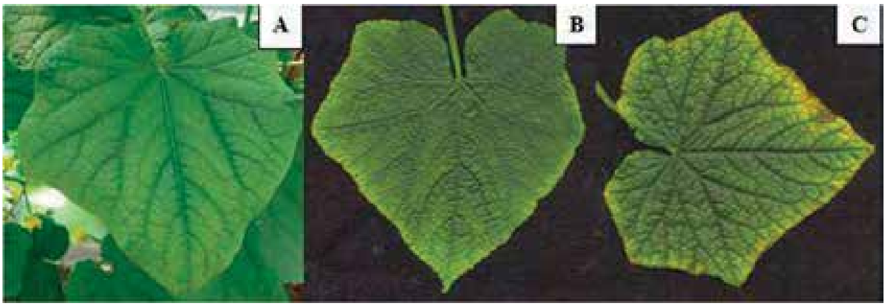

Figure 3. Potassium deficiency in bean pod plants (-K) compared to control (CS). Source: [89].

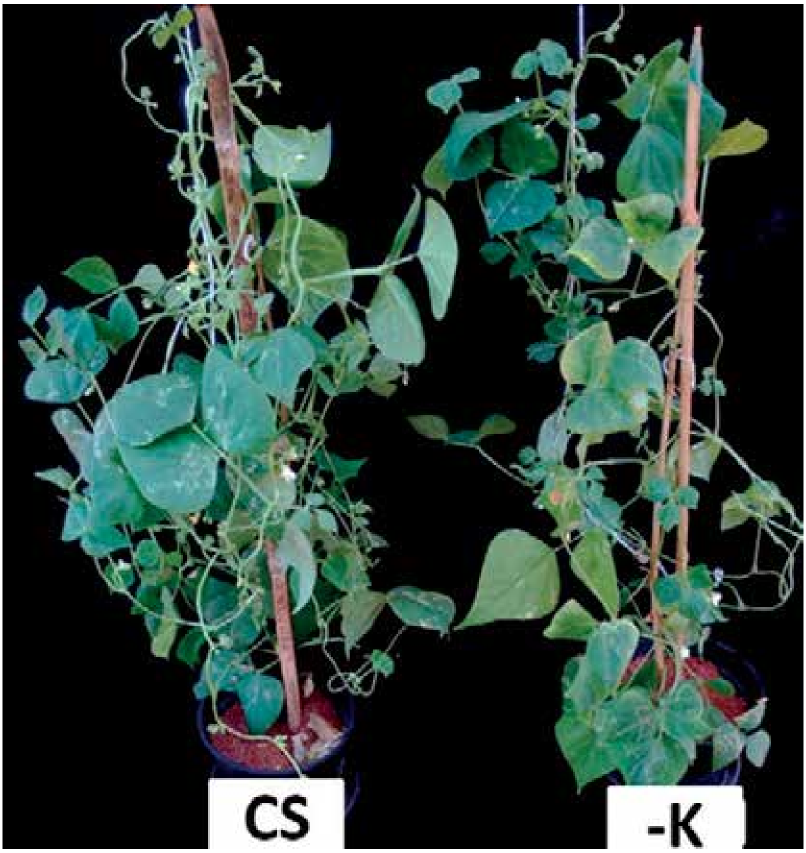

Figure 4. Progressive symptoms of K deficiency in the leaves of the cauliflower "Verona" after being supplied with a nutrient solution without K. Chlorosis and initial necrosis of the nervures (A), advanced stage of necrosis of the nervures (B), and advanced foliar necrosis (C). Source: [88].

However, the molecular changes triggered by K deficiency are not restricted only to old leaves, because in new leaves there is an increase in the levels of oxaloacetate and phosphoenolpyruvate derivatives [86].

In fruits, the deficiency of this macronutrient decreases the glucose, fructose, and sucrose levels, and in plants of Rosaceae family, it decreases sorbitol levels [90], and in species with large amounts of lycopene such as tomato [91], there is less red color intensity due to reduction in the synthesis of this pigment [60, 64].

Several studies have demonstrated the important role of K in plant growth and development, with a considerable decrease in the production of dry mass of plants when K is omitted from culture medium [92]. In sugar beet, the omission of K promoted a considerable reduction of the dry mass of the aerial part and radicular, besides promoting symptoms of nutritional disorders characterized by the appearance of chlorosis markedly red of margins of leaves and evolving toward necrosis until reaching the leaf apex [78].

In other study with cabbage, the omission of K was limiting for the vegetative growth of cabbage, considerably reducing the height of plants, the number of leaves, leaf area, and dry matter of shoot, roots, and whole plant. The deficiency of K, besides promoting a decrease of nutrient content in the aerial part, caused imbalance between the other nutrients and, consequently, morphological alterations, translated as characteristic symptoms of K deficiency [79].

The absence of K in lettuce plants led to reduced growth, with a considerable decrease in height, leaf area, dry mass of shoot, root, and emergence of nutritional disorders [80]. In cultivation under omission of K and eggplants a reduction of dry mass of shoot and root, a decrease of leaf area, height and number of leaves were observed, in parallel to nutritional disorders resulting from the omission of K [93].

The great demand of plants for potassium and their capacity to accumulate this nutrient in the vacuoles makes the observation of symptoms of excess something very rare [23]. When K is excessed, it is also induced to plants; the use of sources such as potassium nitrate and potassium chloride (KNO_3 = 74; KCl = 116) [94] can generate physiological disorders and affect the development of plant. Therefore, experiments with excess of potassium should be recommended sources with lower salt content. In addition, attention should be paid to the effect of accompanying ions that may cause toxicity, and excess K in the nutrient solution may increase or decrease the absorption of other nutrients. The increase of potassium provides an increase in the absorption of nitrate and, on the other hand, can lead to lower absorption of Mg and Ca [23, 94].

9. Potassium in human health and food consumed

K is an essential mineral nutrient for humans because of its important physiological role in conducting electrical impulses in nerve tissue, electrolyte balance of body fluids, and blood pressure control. Ingestion of food of plant origin (i.e., vegetables, grains, cereals, etc.) and animal (i.e., meat, milk, eggs, etc.) are the main sources of K in human food. However, the process of cooking, the increased consumption of processed foods, and the decreased consumption of vegetables and fruits implied a reduction in K intake by the population [95].

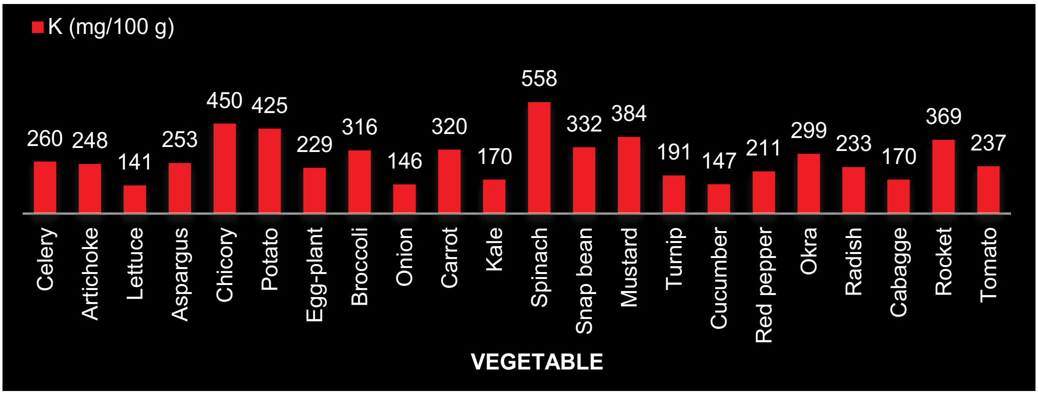

Figure 5. Average potassium content green stuff leafy. Source: [97].

Life stage	Age	Males (mg day^{-1})	Females (mg day^{-1})
Infants	0–6 months	400	400
Infants	7–12 months	700	700
Children	1–3 years	3000	3000
Children	4–8 years	3800	3800
Children	9–13 years	4500	4500
Adolescents	14–18 years	4700	4700
Adults	19 years and older	4700	4700
Pregnancy	14–50 years	–	4700
Breast feeding	14–50 years	–	5100

Source: [98]

Table 2. Reference values for human potassium intake based on age and pregnancy.

A set of clinical and experimental evidence shows the reduction in K intake that is associated with the emergence of various chronic diseases such as hypertension or high blood pressure, an increased risk of cardiovascular disease, kidney disease, and demineralization of bones [95, 96] Thus, the consumption of foods of vegetable origin rich in K as a way to increase K intake and reduce the emergence of diseases associated with malnutrition relative to K intake is recommended. For this, there are several vegetables with varying levels of K in its edible parts (**Figure 5**), whose consumption associated with other food sources can supply the daily need for K intake based on age, sex, and gestation (**Table 2**).

10. Conclusions and future perspectives

This chapter approached the main aspects of potassium nutrition of vegetables and food safety, emphasizing potassium in the context of plant physiology, post-harvest physiology, and human health. In this sense, the cultivation of vegetables under environmental conditions adequate to the development of plants (i.e., phytosanitary management, optimal conditions of temperature, humidity, and luminosity) together with balanced nutrition in K are important factors that contribute to obtaining of foods with nutritional quality. The need for ingestion of foods rich in K and compounds with nutraceutical properties whose production by plant is directly or indirectly influenced by K such as lycopene and vitamin C in tomatoes is taken into account.

In addition, knowing the main biotic and abiotic stresses that can be mitigated by potassium nutrition constitutes an interesting strategy for cultivation and production of vegetables. Therefore, this chapter is proposed as additional information about the tool importance of potassium nutrition in the hydroponic and food safety context to be consulted by students, teachers, and researchers. Considering a modern world and the increase of food consumption processed, these foods still being poor in K foods have contributed to the emergence of diseases related to low intakes of this nutrient.

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Chapter 4

Potassium Fertilization in the Production of Vegetables and Fruits

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Additional information is available at the end of the chapter

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Abstract

Consumption of vegetables worldwide has increased, not only by population growth but also by the trend of changes in consumers' eating habits, making it inevitable to increase production. The consumer of vegetables has become more demanding, having to produce them in quantity and quality, as well as maintaining their supply throughout the year. Hydroponics is an alternative technique of cultivation in a protected environment, in which the nutritious solution is replaced by the nutrient solution. Among the essential mineral nutrients for plants, K stands out for its influence on quality attributes that affect the concentration of phytonutrients critical for human health. It acts as the determinants in the commercialization of vegetables, and can be found in various foods such as vegetables, and fruits. Adequate levels of this nutrient will benefit the consumer's health and also prevent disease. Among the essential plant nutrients, K stands out for its influence on quality attributes that affect the concentration of phytonutrients critical to human health. The horticulturist should prioritize the use of potassic fertilizers with lower salt content, if possible free of chlorine and containing magnesium and sulfur. However, it is essential to remember that the high potassium content in plants can induce deficiency of calcium and magnesium.

Keywords: hydroponics, fertilizers, nutrient management, stress, production

1. Introduction

Plasticulture is a term adopted internationally to designate the use of plastic cover in agriculture, aiming the creation of improved and controlled environments, more propitious to the development of the plants. Vegetables come from the most diverse regions of the world, from arid and desert regions up to the most humid tropical forests, from the icy north to the calico equator, from the sea level to the top of the mountain ranges, and from America to Asia.

The protected cultivation consists of a technique that allows certain control of climatic variables like temperature, humidity of the air, solar radiation, and wind. This control translates into a gain in productive efficiency, reduces the effect of seasonality, favoring a more balanced supply over the months; in addition, the use of this technology allows the effect of seasonality to decrease. This benefit is most evident in regions with a cold climate, as the heat accumulated inside the greenhouses makes it possible to produce certain crops out of season and shorten the production cycle.

The production of vegetables in this type of environment in Brazil is not so recent. In the 1980s, when the production of vegetables began, it was found that, after 3 years of cultivation, many producers could no longer obtain the productivity nor the quality obtained at the beginning of cultivation. At the time, the producers suffered from damages caused by inadequate practices resulting from lack of information and adequate technical assistance. This and other occurrences reinforced the myth that protected cultivation was not feasible. The advance of research, however, showed that the problem was not the system in use but the management adopted.

In countries where protected cultivation is in an advanced stage, the nutritious solution is being replaced by different substrates, with the main objective of circumventing adverse phytosanitary and nutritional factors, allowing strict control of the root environment, especially in relation to water and nutrient management. One of the ways to work around problems of nutritious solution contamination is the use of hydroponic farming systems, in which nutrients are supplied by means of an aqueous solution containing all essential chemical elements to the vegetables.

The main feature of the fertilizers used in hydroponics is that they are soluble in water. One should keep in mind the importance of chemical compatibility between different fertilizers. Macro- and micronutrients are used that are diluted in water to compose up the nutrient solution.

In Brazilian agriculture, potassium (K) is the second nutrient most extracted by vegetables, after phosphorus, which is the nutrient most consumed as fertilizer. The permeability of the plasma membrane makes K to be easily absorbed and transported at long distance by xylem and phloem. Much of the total K of the plant is in the soluble form; therefore, its redistribution is facilitated in the phloem. Thus, under conditions of low K supply through the medium, the element is redistributed from the older leaves to the younger leaves and then transferred to the growing regions. The main biochemical function of K in the plant is enzymatic activation; more than 50 enzymes are dependent on K for their normal activity, such as synthetases, oxidoreductases, dehydrogenases, transferases, and kinases. For leaf and fruit vegetables, several authors have already demonstrated the importance of this nutrient, in addition to increasing production, favoring the improvement of the commercial quality of these products.

2. Objectives

This chapter aims to present the cultivation of vegetables and fruits, their nutrient management in hydroponics and salinity condition, and the role of potassium fertilization on the physiological, biochemicals, and antioxidative quality of vegetables and fruits.

3. Hydroponic cultivation of vegetables and fruits

Hydroponics is an agrotechnology for plant cultivation outside the nutritious solution and in nutrient solution, becoming a promising alternative for the diversification of agribusiness. This system of production provides greater yield per area, lesser incidence of pests and diseases, greater ease of execution of cultivation practices, better programming of production, and shorter cycles, due to better environmental control [1].

Among the different hydroponic systems that do not use substrates, the Nutrient Film Technique (NFT) system is the most widespread in Brazil and worldwide [2]. This technique favors the continuous or intermittent circulation of the nutrient solution in cultivation channels, which may have varying dimension sizes and made by different materials, poly(vinyl)chloride (PVC), polyethylene, polypropylene, asbestos, and masonry being the most widely used [3]. Currently, hydroponic cultivation has great importance in several countries, such as Holland, the United States, France, Spain, Japan, and Israel among others. However, one must consider the cost of implementation and the high level of technology required in this system.

The most planted vegetables in this system are lettuce, arugula, and tomato. Other vegetables are restricted to smaller areas, such as cress, parsley, peppers, strawberries, and melons. In general, hydroponic crops require permanent monitoring, mainly as regards the uninterrupted supply of electricity and the control of the chemical and physical characteristics of the nutrient solution [4].

All essential nutrients must be supplied at levels compatible with the requirements of each species, according to the development stage [5]. In order to minimize experimental errors in the analysis of symptoms induced by excess or deficiency nutrient in nutrient solution, it is recommended to use minimum concentrations [6]. The definition of these minimum concentrations should be studied in view of the genotypic, environmental, and demand differences associated with the different phases of development. In general, there is a tendency to reduce the ionic concentration of the nutrient solution in commercial hydroponic crops, especially in environments whose temperature, luminosity, and relative humidity are high in the hottest seasons of the year [7].

It is worth mentioning that the rational use of fertilizers, in addition to reducing costs and guaranteeing production quality, minimizes contamination of the environment and its consequences. These are the eutrophication of surface and groundwater and the accumulation of high levels of nitrate in the groundwater and plants [8]. In the handling of the nutrient solution, factors such as temperature (optimum levels around 24°C), pH (suitable values between 5.5 and 6.5), and electrical conductivity (EC) of the nutrient solution (optimum range between 1.5 and 4.0 dS m^{-1}) should be monitored and controlled periodically [9].

4. Nutrient solution management

One of the basic principles for plant production is the provision of all the nutrients the plant requires [9]. In this environment, when nutrient imbalance occurs, production will be limited. For the adequate development of the cultures, macro-and micronutrients that are essences for the growth and production of the plants are necessary, which are presented in **Figure 1**.

That division, between macro- and micronutrients, takes into account the amount that the plant requires of each nutrient for its cycle, all being equally important in nutritional terms. In this way, it is important to observe that the total amounts absorption are of secondary importance since, in hydroponic cultivation, the concentration of nutrients in the growth medium is maintained constant, which does not occur when cultivated in the nutritious solution.

The optimum pH values for the nutrient solution are between 5.5 and 6.5, being important to keep these values in the solution to favor the availability of nutrients to the plants. If the pH is above 6.5, elements such as phosphorus, manganese, and iron begin to precipitate, remaining

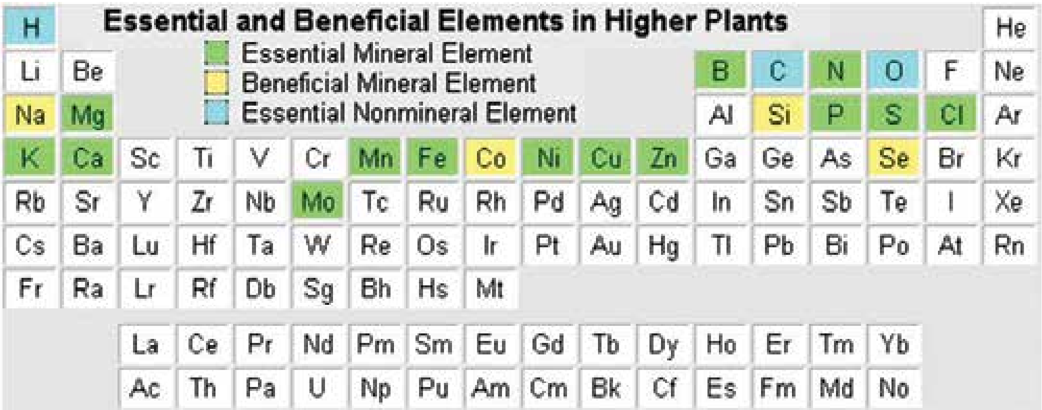

Figure 1. Chemical elements used in plant production [3].

in forms unavailable to plants. If the pH is lower than 5.5, magnesium, calcium, and molybdenum, in particular, have reduced availability, as shown in **Figure 2**.

Using a conductivity meter, we established the ability of the nutrient solution to conduct the electric current. As this capacity changes according to the content of the mineral salts, the value of the electric conductivity allows estimating the total concentration of the nutrients in the solution. The higher the EC, the higher the content of mineral salts in the nutrient solution. Normally, when the electrical conductivity is reduced to a certain level of the initial solution (about 30–50%), it is advisable to replace it. The level at which EC value should be maintained varies according to climate and culture.

The pH and EC characteristics of the water used and then of the nutrient solution (water and nutrients diluted in it) should be those indicated for each type of crop. In theory, pH may range from 0 to 14, but in practice, extreme values are incompatible with plant life. Second to the pH values, the quality indexes for the water used in hydroponics can be classified (**Table 1**).

In preparing the solutions, fertilizers contain macronutrients that must be weighed in the correct amount, indicated by the chosen formulation, then diluted one by one in the tank with water to approximately two-thirds of its capacity. Posteriorly, added the micronutrients are in the form as concentrated solution, in finally, the solution is added with chelated iron. The main fertilizers used for the preparation of nutrient solutions are found in **Tables 2** and **3**.

Table 4 presents the adapted solutions [3] for use in the preparation of the nutrient solution in the NFT system, for leafy vegetables and fruits.

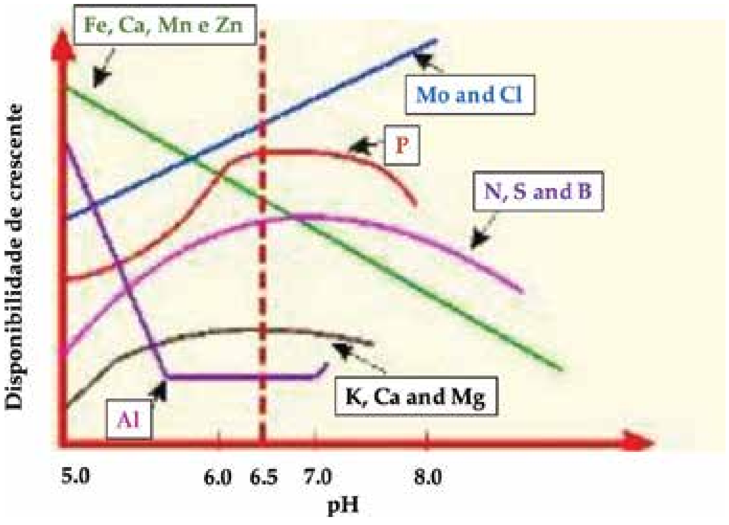

Figure 2. Relationship between pH and element availability.

Units	Good	Acceptable	Maximum limit
EC mS cm	<0.75	<0.75–1.50	2.0
pH	6.50	6.80	7.5
HCO^{-}_{3} mmol L^{-1}	1.60	3.30	7.5
Na^{+} mmol L^{-1}	0.87	1.30	2.61
Cl^{-} mmol L^{-1}	1.14	1.71	2.86
SO^{2}_{4} mmol L^{-1}	0.83	1.26	2.08
Ca^{+2} mmol L^{-1}	6.50	10.00	14.00
Fe µmol L^{-1}	—	—	0.08
Mn µmol L^{-1}	—	—	0.04
Zn µmol L^{-1}	—	—	0.02
B µmol L^{-1}	—	—	0.03

Table 1. Quality indices for water used in hydroponics [3].

Fertilizers	Nutrient %					
	N	P	K	Ca	Mg	S
KCl	—	—	49.8	—	—	—
$NH_4H_2PO_4$	10.0	21.8	—	—	—	—
$NH_4H_2PO_4$	11.0	21.8	—	—	—	—
$Ca(H_2PO_4)_2H_2O$	—	24.6	—	15.9		
KH_2PO_4	—	22.8	28.7	—	—	—
NH_4NO_3	34.0	—	—	—	—	—
$Ca(NO_3)_24H_2O$	15.0	—	—	20.0	—	—
$Mg(NO_3)_26H_2O$	7.0	—	—	—	6.0	—
KNO_3	13.0	—	36.5	—	—	—
$NaNO_3$	16.0	—	—	—	—	—
$(NH_4)_2SO_4$	20.0	—	—	—	—	24.0
$CaSO_4 \cdot 2H_2O$	—	—	—	21.4	—	17.0
K_2SO_4	—	—	41.5	—	—	17.0
$MgSO_4 \cdot 7H_2O$	—	—	—	—	9.7	13.0
$K_2SO_4 \cdot 2MgSO_4$	—	—	18.2	10.8	—	22.0

Table 2. Main sources of macronutrients used for the preparation of nutrient solutions.

Fertilizers	**Nutrient %**					
	B	**Cu**	**Fe**	**Mn**	**Mo**	**Zn**
H_3BO_3	17.0	—	—	—	—	—
$Na_2BO_2 \cdot 10H_2O$	11.0	—	—	—	—	—
$CuCl_2 \cdot 2H_2O$	—	37.0	—	—	—	—
$MnSO_4 \cdot H_2O$	—	—	—	43.0	—	—
$ZnCl_2$	—	—	—	—	—	48.0
$FeCl_3 \cdot 6H_2O$	—	—	21.0	—	—	—
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	—	—	—	—	54.0	—
$NaMoO_4 \cdot 2H_2O$	—	—	—	—	34.0	—
$CuSO_4 \cdot 5H_2O$	—	25.0	—	—	—	—
$MnSO_4 \cdot 7H_2O$	—	—	—	32.0	—	—
$ZnSO_4 \cdot 7H_2O$	—	—	—	—	—	20.0
$Na_2B_4O_7 \cdot 5H_2O$	14.0	—	—	—	—	—
MoO_3	—	—	—	—	66.0	—

Table 3. Main sources of micronutrients used for the preparation of nutrient solutions.

Culture	**N–NO_3^-**	**P**	**K**	**Ca**	**Mg**	**S**	**B**	**Cu**	**Fe**	**Mn**	**Mo**	**Zn**
	mg L^{-1}											
Lettuce	238	62	426	161	24	32	0.3	0.05	5.0	0.4	0.05	0.3
Tomato	169	62	311	153	43	50	0.2	0.03	4.3	1.1	0.05	0.3
Pepper	152	39	245	110	29	32	0.3	0.03	3.7	0.4	0.05	0.3
Eggplant	179	46	303	127	39	48	0.3	0.05	3.2	0.6	0.05	0.3
Cucumber	174	56	258	153	41	54	0.2	0.03	4.3	1.1	0.05	0.3
Melon	170	39	225	153	24	32	0.2	0.03	2.2	0.6	0.05	0.3
Strawberry	125	46	176	119	24	32	0.2	0.03	2.5	0.4	0.05	0.3

Table 4. Values of mineral nutrients in nutrient solutions used for the NFT system.

5. Potassium salinity in nutrient solution and its effects on metabolism

Potassium is an essential nutrient for all living beings, playing a key role in photosynthesis, which is the transformation of light energy into chemical energy (ATP and NADPH). As all vital plant functions depend directly or indirectly on ATP and NADPH, the influence of K on plant metabolism becomes evident. It also plays an important role in the activation of more than 60 enzymes, which act on several metabolic processes such as photosynthesis, protein synthesis, and carbohydrates, also affecting water balance and the growth of meristematic tissues [10].

K absorbed by the root is led to the aerial part by the xylem and phloem, its internal redistribution is quite easy. The element is directed from the older leaves to the younger leaves, to the growing regions and to the fruits. This is due, in part, to the fact that about 75% of plant potassium is soluble in tissues.

Cultures differ in their K requirements because of differences in the physiological functions in which K is involved. Cultures where the harvested part consists of young plant tissue, as is the case of leafy vegetables and fruits, have high requirements of K per unit of dry weight produced. When the same crop is harvested at the complete maturation stage, the requirement for potassium per dry weight unit is substantially lower. Cultures that produce fleshy fruits or storage organs have high K requirement when compared to cereals [11].

Among the various functions of potassium in plants, water use efficiency is better cited, as a consequence of the control of the opening and closing of the stomata, greater translocation of carbohydrates from the leaves to the other organs of the plant, and improved enzymatic efficiency and commercial quality of crops [12].

Relative quantitative evaluations for a particular mineral element can be achieved through the profile scanning of stomata. This type of comparisons between elements can only be made by applying calibration factors. In this way, K contents of guard cells of the opened and closed stomata can be measured. In opened stomata, there is more K, and there is more Cl than the closed one but the differences are not so great. On the other hand, P contents are almost the same.

Comparison of the traces and stomata indicates, as might be expected, that the P peaks coincide with the nuclei [13] (**Figure 3**).

Potassium also increases the natural resistance of the aerial part of plants, the fungal diseases, pests, damping-off and counter balances the effect of excess nitrogen absorption. However, excess potassium imbalances the nutrition of vegetables, making it difficult to absorb calcium and magnesium [13].

K is required for protein synthesis; when plants are deficient in K, there is less protein synthesis and accumulation of soluble nitrogen compounds, such as amino acids, amides, and nitrates. Thus, the proper use of nitrogen fertilizers depends, also, on an efficient supply of potassium to the plants. The supply of potassium fertilizers to the crops, besides affecting the production, also has an effect on the quality of the harvested fruit. Specifically for tomato, these qualitative characteristics are important both for use in industry and for consumption "in natura." In tomato, the fruit's flavor is determined by the amount of solids, mainly sugars and organic acids, and volatile compounds. Considering that, in the ripe fruit, 95% of its constitution is water, only a small amount of solid matter will determine its quality [14]. The decrease in the sugar contents correlates with high doses of nitrogen, which leads to the hypothesis that the apical pruning, associated to the various doses of N and K, can influence, in a certain moment, the level of substances in the fruits [14].

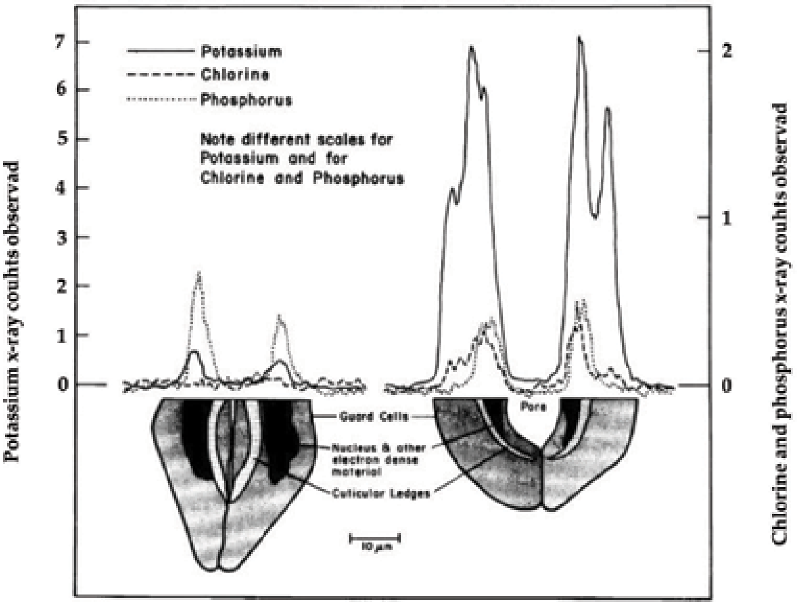

Figure 3. Profiles of relative amounts of K, Cl, and P across an open and a closed stoma. The traces are the result of scanning a 0.5–1 μm diameter beam across the stomata shown diagrammatically below the traces. In order to indicate the profile scanned, the images of the stomata have been cut off in this diagram where the beam crossed the guard [13].

The salinity of the nutrient solution is quantified by the electrical conductivity, which at varies function to the culture and nutrient balance in the solution. Once salts are diluted in the solution, the producer cannot identify which element is causing increasing osmosis power. The salinity in vegetables grown in the hydroponic system causes lower growth in plants, which is also due to the reduction in the absorption of some of the main nutrients, mainly Ca and K [15].

Plants are very sensitive to salinity where they absorb water having high contents of salts, which causes toxicity. This excess absorption promotes imbalances in the cytoplasm, causing damages to appear mainly at the edges and at the apex of the leaves, regions where the accumulation of absorbed salts occurs [16].

Imbalances may be the result of the salinity effect of nutrients above the required, or may be caused by physiological inactivation of an essential nutrient when it increases its internal requirement in the plant [17].

In a yield response curve, there is a point at which maximum production is reached and maintained at that level until an ionic concentration is reached in the solution, where production begins to decrease. This interval, between nutritional deficiency conditions and toxicity, depends particularly on the nutrient and nutritious solution salinity conditions [18].

Lower absorption of K by vegetables has been attributed to the higher competition between Na and K by the absorption sites or a higher flow of K from the roots. The reduction in K concentration, under saline stress, is an additional complicator for plant growth, since in some situations this element is the main nutrient contributing to the decrease of osmotic potential [19].

In relation to calcium, it has been demonstrated that increased salinity may induce its deficiency [20]. The reduction in Ca^{2+} absorption may lead to loss of plasma membrane integrity, with consequent loss of the absorption capacity of some ions, especially K^+ [21]. Salinity-tolerant varieties tend to have higher K^+ transfer rates and only slight reduction in Ca^{2+} transfer to aerial part, in order to maintain a positive relationship between those nutrients and Na^+ and Cl^- ions [22].

The high salinity of some fertilizers, mainly of KCl, compromises the growth and distribution of the roots, as well as the absorption of water and nutrients [23]. Potassium chloride is the main source of K for agriculture, followed by potassium sulfate used on a smaller scale. Potassium sulfate has a lower salinity effect than potassium chloride, which makes it more suitable for the preparation of nutrient solutions [24].

Plants undergo changes in their metabolism when maintained under adverse environmental conditions. Plant tissues are endowed with different response systems to control the production of free radicals. Due to their specific compartmentalization in the cells, the enzymes and organic compounds formed in situations of environmental stress can be determined. In saline conditions, there is a reduction in the availability of water to the plants; as water tends to move from point larger to the smaller the osmotic potential (of the salinized nutritious solution toward the plant), there will be greater energy expenditure for its absorption. The greater or lesser effort to overcome the osmotic potential difference varies according to vegetable species for adaptation to different salinity conditions [25]. In addition, this factor may influence the photosynthetic process, since the content of chlorophyll in the plants will be affected [26].

The high saline concentration in the solution can cause nutritional imbalance, toxicity of some ions, and interference in the hormonal balance, which are able to decrease the plasticity of the cell, causing reduction in the permeability of the cytoplasmic membrane.

The role of calcium in vegetable adaptation to saline stress is complex and not well defined. Saline stresses were observed in the positive effects of this nutrient. The effects of K and Mg are little studied because they have a beneficial effect on the plant to increase the tolerance of vegetables to salinity in the nutrient solution [27].

Applications of high and continuous doses of KCl may also raise the chloride ion content in the plant, leading to a chlorosis and necrosis of the leaves, as well as a drop in production. Chlorine does not enter into the constitution of organic compounds, being necessary for the photolysis of water, during photosynthesis and electron transport [28].

When applied externally, Ca^{+2} decreases saline stress by means of an unknown function that preserves K^+/Na^+ selectivity and inhibits K^+ absorption sites, which can reduce the Na^+ influx mediated by the K^+ absorption low-affinity component. Calcium is usually maintained in the cytoplasm at 100–200 mol m^{-3} by active transport, and NaCl promotes a rapid increase in its concentration in the cytoplasm, probably acting as a signal of general stress. Although there is no confirmation that this increase is a salinity tolerance effect, the higher concentrations of Ca^{+2} in the cytoplasm may be transient. Results suggest that this increase, as a function of exposure to NaCl, may be reduced by the increase in Ca-ATPase activity [29]. The eggplant presents resistance to salinity induced by potassium sources, being considered a plant that can be used in conditions of high osmotic potential [24].

6. Potassium affecting plant growth and yield

Salinization is a problem that invariably occurs in protected environments, due to the accumulation of salts present in fertilizers. This problem tends to aggravate over time with greater or lesser speed, according to the practices adopted. The effects of salinity on fruit and leaf vegetables are intense, causing flowers to fall, alteration of the fruits color, flowers abortion, and burn on leaf margins [30] (**Figure 4**).

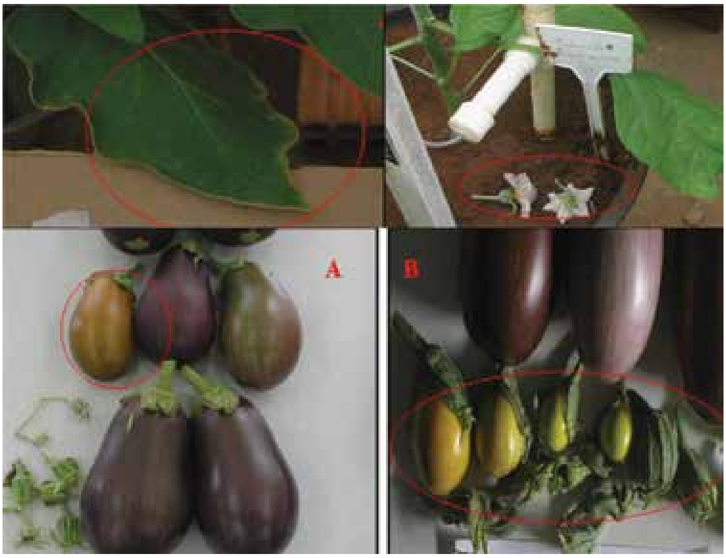

Figure 4. Images of the effects of salinity on eggplant.

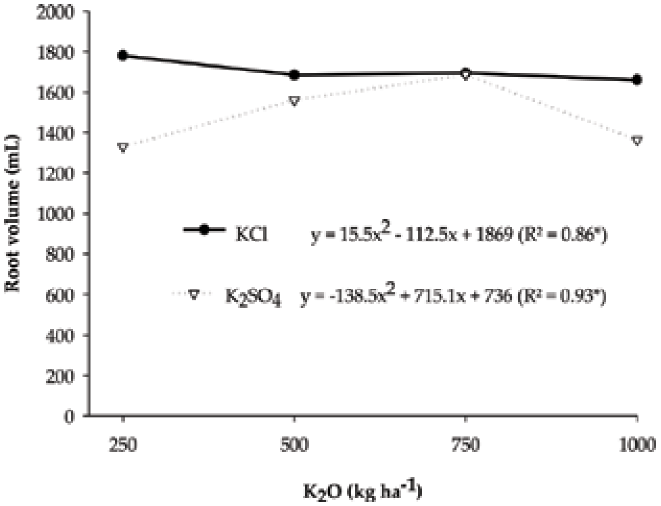

Figure 5. Root volume of eggplant (*Solanum melongena* L.), cultivar Embu, as a function of potassium doses and sources.

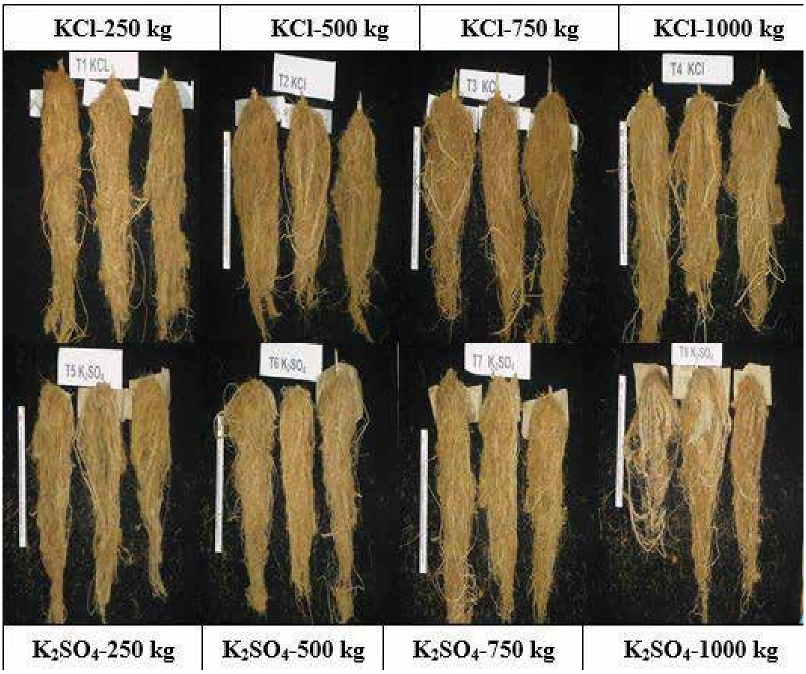

Figure 6. Roots of plants of eggplant (*Solanum melongena* L.), grow crops "Embu," according to doses and potassium sources.

Comparatively higher root volume was found when potassium chloride was used as the source of potassium fertilization than potassium sulfate (**Figures 5** and **6**). Considering the use of K_2SO_4, it is observed that the root volume increases with increasing doses, up to an estimated maximum value of 645 kg ha^{-1} K_2O; from here, there is a decrease, indicating a stressing effect on the plant. On the other hand, with KCl as source there is no definite trend of increase or decrease in the root volume, values found being stable and higher than those found with the K_2SO_4 source [30].

7. Cation dynamics in leaves and fruits of vegetables

Many problems have been observed related to excessive fertilization, leading the nutritious solution to an accumulation of salts. Although the water used in irrigation in the protected crop is of good quality, using the fertigation technique increases the risk of salinization [31].

In the process of nutrient absorption, the cationic interactions at the adsorption sites and the concentration of nutrient ions in the solution are important aspects in plant nutrition and crop production. The rate of absorption of a nutrient by the plant depends on the cations dissolved in the solution in dynamic equilibrium with the cations of the nutritious solution exchange complex [32]. The absorption of a nutrient is also affected by the nature of the complementary cations, that is to say, there is influence of an ion adsorbed in the release of another ion to the solution, besides the relations that involve the cations [33].

The elevation of K content in the solution can induce nutritional imbalance for the plants, due to antagonism, competitive inhibition, and noncompetitive inhibition among nutrients, in addition to synergism, which can cause a differentiated dynamics between cations in the leaves and roots of plants. However, little is known about the interactions between cations caused by excess doses of K_2O induced by different sources. When the K_2O doses are increased, regardless of the source used, the electrical conductivity increases linearly (**Figure 7**). However, it is observed that the values of electrical conductivity are significantly higher with the use of KCl, indicating an increase in nutritious solution salinity [34].

The electrical conductivity ranges between 3.82 and 1.33, with a mean of 2.49 dS m^{-1} when a dose of K_2O 250 kg ha^{-1} for KCl fertilizer was applied, whereas values were between 4.24 and 0.86 dS m^{-1} and averaged 2.55 dS m^{-1} for K_2SO_4 (**Figure 8A**). A decreasing trend of electrical conductivity was evidenced during the experimental period, and this reduction was more pronounced during 60 days after transplantation because of the onset of flowering and fruiting. In case of K_2O 500-kg ha^{-1} KCl dose, the electrical conductivity ranges between 3.46 and 0.89 dS m^{-1} and the average of 2.16 dS m^{-1}, while the range was between 3.30 and 0.28 dS m^{-1} with a mean of 1.79 dS m^{-1} for K_2SO_4 as potassium source (**Figure 8B**). A greater fluctuation of electrical conductivity was observed after K_2O 750 kg ha^{-1} especially for KCl, and the range was as high as 6.27 and as low as 1.30 having an average of 3.78 dS m^{-1} (**Figure 8C**). When K_2SO_4 was applied, electrical conductivity values obtained were between 4.27 and 1.03 dS m^{-1} with a mean of 2.65 dS m^{-1}. Subsequently, at a dose of K_2O 1000-kg ha^{-1} electrical conductivity in KCl and K_2SO_4 treatments remained within the ranges from 7.12 to 1.82 and from 3.36 to 1.25 dS m^{-1} (**Figure 8D**), with a mean of 4.47 and 2.11 dS m^{-1}, respectively [35].

The use of K_2SO_4 as a source of potassium fertilization generates a direct form of competition with Mg^{2+} in the roots of eggplants, high doses of K_2O affect production, and excess K induces

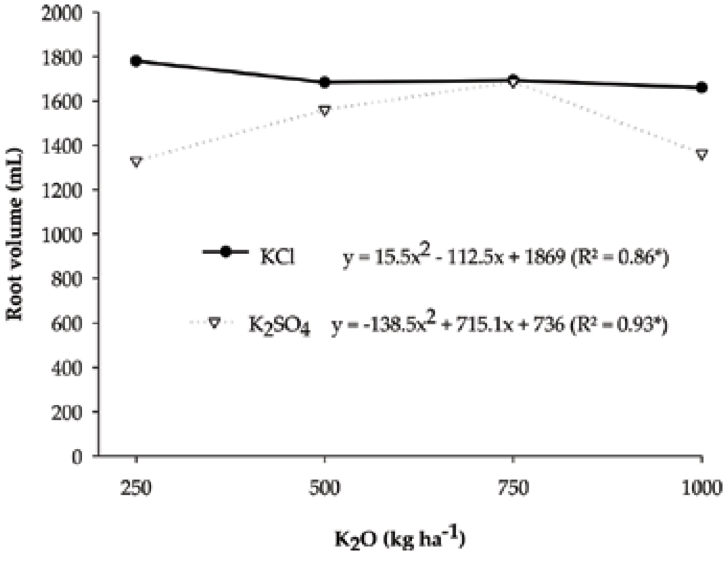

Figure 7. Electrical conductivity (EC) in function to sources and potassium doses.

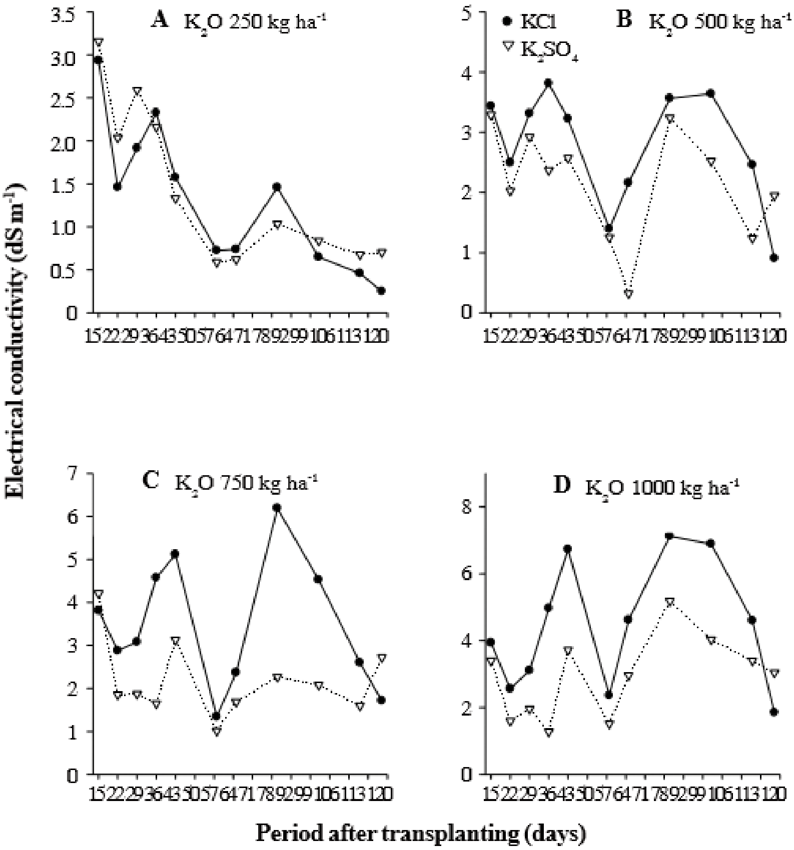

Figure 8. Electrical conductivity (EC) corrected for function and the sources and doses 250 (A), 500 (B), 750 (C) and 1000 (D) kg K_2O (KCl and K_2SO_4) in relation to the days after transplantation (DAT).

competitive inhibition between cations; however, the use of K_2SO_4 is less harmful, when used in excess, than that of KCl [34].

The elements are absorbed by the plants at different speeds, generally following the decreasing order as follows:

1. Anions—$NO_3^- > Cl^- > SO_4^{2-} > H_2PO_4$
2. Cations—$NH_4^+ > K^+ > Na^+ > Mg^{2+} > Ca^{2+}$

The accompanying ion, as a consequence of this, also influences at the absorption of its pair, so, for example, the maximum absorption of NH_4^+ will occur when it is accompanied by NO_3^-, the speed will be minimal if accompanied by $H_2PO_4^-$. **Table 5** presents examples of interionic effects.

The inhibition consists in the reduction of the mineral absorption due to the presence of another one, being considered competitive inhibition when the element and the inhibitor

Ion present	Second ion	Effect of the second on the first
Mg^{2+}, Ca^{2+}	K^+	Competitive inhibition
$H_2PO_4^-$	Al_3^+	Not competitive inhibition
K^+, Ca^{2+}	Al_3^+	Competitive inhibition
$H_2BO_3^-$	NO_3^-, NH_4	Not competitive inhibition
K^+	Ca^{2+} (high concentration)	Competitive inhibition
SO_4^{2-}	SeO_4^{2-}	Competitive inhibition
SO_4^{2-}	Cl^-	Competitive inhibition
MoO_4^{2-}	SO_4^{2-}	Competitive inhibition
Zn^{2+}	Mg^{2+}	Competitive inhibition
Zn^{2+}	Ca^{2+}	Competitive inhibition
Zn^{2+}	$H_2BO_3^-$	Not competitive inhibition
Fe^{2+}	Mn_2^+	Competitive inhibition
Zn^{2+}	$H_2PO_4^-$	Competitive inhibition
K^+	Ca^{2+} (low concentration)	Synergism
MoO_4^-	$H_2PO_4^{2-}$	Synergism
Cu^{2+}	MoO_4^{2-}	Not competitive inhibition

Table 5. Examples of interionic effects [36].

are disputed at the same site of the carrier in the membrane. No competitive inhibition happens when binding occurs at different sites of the carrier. In the first case, the effect of the inhibitor can be annulled by increasing the concentration of the inhibited element, which does not occur at the second case. An example of competitive inhibition is observed between Ca, Mg, and K [36].

Synergism occurs when the presence of one element enhances the absorption of another, for example, Ca^{2+} in low concentrations increases the absorption of cations and anions (Viets effect), due to its role in maintaining the functional integrity of membranes, which has a consequence in the practice of fertilization; another example is Mg^{2+} which increases the absorption of phosphorus [36].

The black bottom or rot apical of the tomato (**Figure 9**) is a very common anomaly in fruits. It can cause high losses, above 50% of the fruits produced, especially in the lower parts. It is characterized by black spots, hard and dry in the apical extremity, and well visible from the formation of the fruits. The main cause is the lack of calcium in the tissue, caused by the competitive inhibition between K, Ca, and Mg, which causes Ca deficiency. This anomaly occurs very frequently in tomato culture in hydroponic system, because of the accelerated growth of plant, due to the environment conditions and the fact that calcium is still in the plant's phloem. This problem is aggravated when water deficiency occurs.

Figure 9. Physiological anomaly called black bottom or apical rot.

8. Changes in leaf proline protein induced by potassium

The proline concentration was significantly modified independently of potassium source, and higher level in this parameter occurred under potassium rate of K_2O 1000 kg ha^{-1} [35], as shown in **Figure 10A**. As for the protein content, with the increase in K_2O concentration there was a reduction in the content (**Figure 10B**).

Under normal conditions, proline is produced using glutamate and arginine while glutamate is the main pathway in stress conditions [37]. When plant experiences stress such as inadequate situations of mineral, salt, and water, proline protects the cell against denaturation processes, because this organic compound is highly soluble in water. It is accumulated in the cytoplasm of cells present in leaves, stems, and roots. Abiotic stresses like salt stress to *Oryza sativa* plants showed several biochemical consequences at different proline levels [38]. Significant changes in *Glycine max* plants under water deficit as an abiotic stress [39] were also found.

Some authors affirm that proline has functions linked to processes of adaptation to water deficit; however, others point to proline as an indicator of stress. Although there is no clear evidence of proline accumulation in tolerant species, its accumulation in species sensitive to water deficit has been observed, and this mechanism seems to be part of the protection against this type of stress [40].

The synthesis of proline has special importance in plants, because it is closely related to the water potential of the tissues. Plants in conditions of water stress or saline have high levels of proline compared to plants under normal conditions. This phenomenon seems to be related to the mechanism of protection against lack of water, because proline helps reduce the water potential of tissues and thus retain water. It is not by chance that the solubility of proline is much superior (162 g in 100 mL) than that of the other protein amino acids (in the range of <1–25 g in 100 mL). Although the two proline synthesis pathways are equally important under normal conditions, the evidence is more favorable to direct glutamate pathway (without acetylation) in water stress conditions [39].

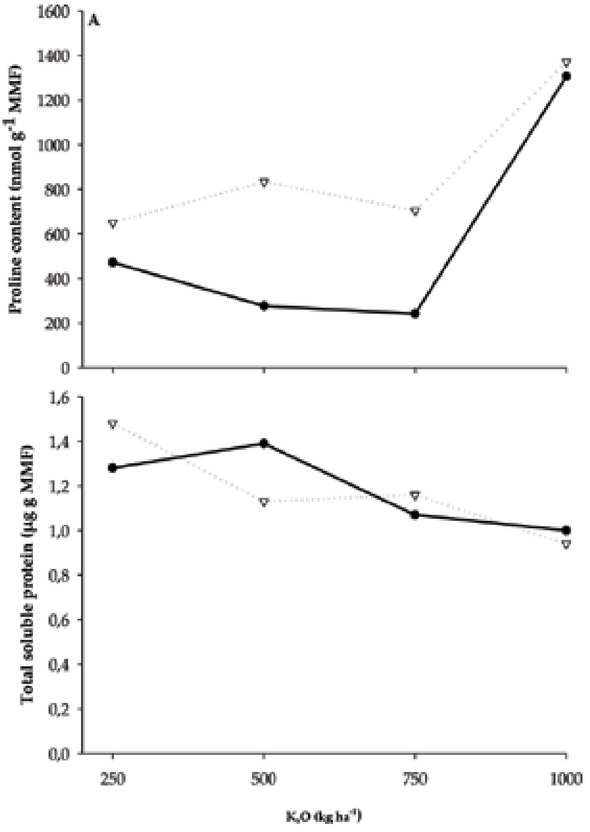

Figure 10. Concentration of proline (A) and soluble protein (B) in the gram of fresh matter mass (MMF) in function to the sources and doses of potassium.

In tomato culture, the accumulation of proline was detected within the first 24 h of the beginning of the treatment with excess fertilizers, observing its osmoregulatory activity. Halophytic or glycophytic plants adapt to high saline concentrations by lowering the osmotic potential of their tissues, with increased solutes absorption (Na and Cl ions). However, in less tolerant species, the growth is inhibited in function to the toxic effect of the accumulation of solutes [41].

9. Effect of potassium sources on the antioxidant activity

Plants have a high requirement for K for mainly maintaining a high K content in the cytoplasm, mainly to ensure enzyme activity [42]. A high concentration of K in cytosol and chloroplast stroma is also required to maintain anion neutralization and an appropriate pH level for cell functioning [21]. It can also participate in the control of stomatal opening and closing which is essential for photosynthesis. Despite the great importance of K, excess of it can reduce the osmotic potential of the solution, making the nutritious solution saline, resulting in a modified nutritious solution in which the growth of most species is prejudiced by the presence of high concentrations of soluble salts, exchangeable Na, or both in the rhizosphere [43]. Among the potassium fertilizers available on the Brazilian market, KCl is the most popular. Besides, K_2SO_4, $K_2SO_4{\cdot}2MgSO_4$, and other K sources are widely used in different agricultural segments in Brazil [44]. The above K source fertilizers produce different levels of salinity in nutritious solution, as, for example, KCl has a higher salt content than K_2SO_4. In the case of potato and eggplant, KCl application has resulted in lower yields compared to K_2SO_4 [41].

The enzymatic activity of catalase (CAT) is an enzyme that increases the rate of dismutation of the superoxide radical in hydrogen peroxide and is considered as an antioxidant enzyme (reactive oxygen species—ROS). CAT activity increases with increasing K_2O concentrations (**Figure 11**). High rates of KCl and K_2SO_4 increased the proline concentration at higher doses and reduced the protein concentration (**Figure 10**). The proline content of the leaf and the development of the eggplants are larger for the K_2SO_4 source [41].

Salinity can restrict the absorption of water and nutrients, reduce photosynthetic processes, and increase respiration, inducing a reduction in plant growth [45]. In the case of water deficit, the activity of the enzyme system and the production of compounds related to the antioxidant system of plants are altered [46]. This plant response occurs due to excessive accumulation of ROS in plant cells, in particular of superoxide, hydroxyl radical, and hydrogen peroxide [47]. Salinity can promote an intense ROS production that can lead to the degradation of proteins and membranes, reducing photosynthesis and plant growth [48]. Among the enzymatic mechanisms involved in detoxification of ROS, there are the isoforms of the enzyme such as superoxide dismutase (SOD), CAT, ascorbate peroxidase (APX), and peroxidase phenols (POX). SOD acts by converting O_2 into H_2O_2 and is localized mainly in the mitochondria and chloroplasts. These organelles generate most of the ROS in plant cells [49]. Peroxidases and catalases convert

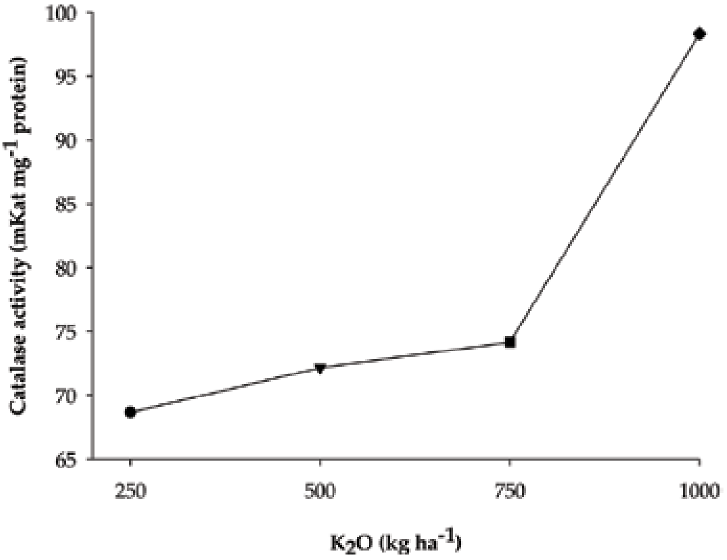

Figure 11. Catalase activity (mKat mg^{-1} of protein) as a function of potassium sources and doses.

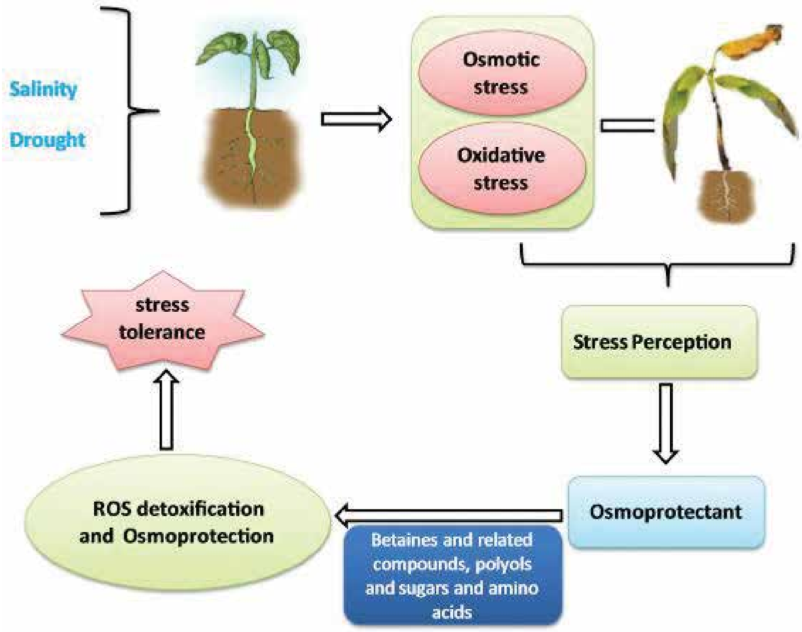

Figure 12. A general scheme of salt and drought stress tolerance in plants.

H_2O_2 into water and molecular oxygen, which are harmless to plants. Although the salinization leads to the production of ROS, at certain concentrations, K has an effect of reducing the harmful effects of salinization and ROS, mitigating stress effects [50]. This effect has been widely investigated in view of the need to understand its relationship with salinity and stress tolerance better. **Figure 12** [51] shows the general scheme of salt and drought stress tolerance in plants. Some osmolytes are involved in salt and drought stress tolerance through osmoprotection and ROS detoxification. They protect the plant from osmotic and ionic stresses [51].

10. Potassium increases crops quality

K is usually the most abundant cation in the cultures, being found in the tissues in greater proportion in the ionic form (K^+). K stimulates vegetation and tillering (grasses); increases the content of carbohydrates, oils, fats, and proteins; stimulates the filling of the grains, reducing the chopping; promotes storage of sugar and starch; helps symbiotic N fixation; increases the use of water; and increases resistance to droughts, frosts, pests, and diseases. As K improves the quality of agricultural products, it is described as the “quality nutrient.” It is interesting to note the high correlation of K and proteins in the seeds of several cultivated plants, since cultures with high protein contents require (and export) large amounts of K through the grains.

Among the essential mineral nutrients for plants, K stands out for its influence in quality attributes that affect the concentration of phytonutrients critical for human health. However, many plants, nutritious solutions, and environmental factors often limit the absorption of K from the nutritious solution in sufficient quantity to optimize the quality attributes mentioned earlier [52].

K is a nutrient particularly required by carbohydrate-producing plants, as it participates in the photosynthetic process, transports carbohydrates from the leaves to the tuber or stalk, and activates the starch synthetase enzyme. In sugarcane, research results have shown a close relationship between the K content in the stems and with the sugar production. In the soybean culture, increased potassium fertilization promotes an increase in the grain protein content and a reduction in the oil content. This one fact can be understood by the participation of K in the process of protein synthesis in the plants. For citrus cultivation, it was observed that the increase of the K content in the leaves increases the size, the production, and the number of fruits. It also increases the vitamin C content and the percentage of acid in the juice, and decreases the concentration of soluble solids and the percentage of juice and solids/acid in the fruit.

The acidity in the tomato and the solids and starch content in the potato are positively correlated with the potassium fertilization, which also affects the composition and quality of strawberry, grape, grapefruit, pistachio, watermelon, and tomato. Generally, K appears to affect acidity, the pH, and carotenoid content. In tomato, the increase of K in the nutritive solution improves the color of the pulp and increases the content of lycopene, which is the carotenoid responsible for the red color of tomato and watermelon [53].

Lycopene is not essential for humans and animals, but research shows that it is then beneficial because it has antioxidant properties, which neutralizes free radicals that can cause cell damage. Lycopene is the most sensitive pigment to K deficiency, since K being an essential cofactor for protein synthesis, its deficiency could lead to reduced rates of enzymatic reactions involved in the synthesis of carotenoids and their precursors [54].

11. Final considerations

Potassium presents many important functions in leaf and fruit vegetables, including enzymatic activation, regulation of the osmotic potential of cells, cell expansion, and opening and closing of the stomata, being the nutrient that most affects the quality of leaf and fruit vegetables. Due to potassium performance in several physiological processes, especially in the enzymatic activity, its adequate nutrition is fundamental for the development and quality of the vegetables. The horticulturist should prioritize the use of potassic fertilizers with lower salt content, if possible free of chlorine and containing magnesium and sulfur. However, it is essential to remember that the high potassium content in plants can induce deficiency of calcium and magnesium.

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Cultivation Methods for Leafy Vegetables and Tomatoes with Low Potassium Content for Dialysis Patients and the Change of those Qualities

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Additional information is available at the end of the chapter

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Abstract

It is recommended that kidney disease patients receiving dialysis have limited potassium intake including intake of vegetables with high potassium content. Dialysis patients cannot absorb other nutrients contained in vegetables. To solve these problems, methods of cultivating vegetables with low potassium contents as compared to normal vegetables were studied. In leafy vegetables, the potassium contents were reduced as much with 60–70% by the cultivation without potassium applications during the latter half of the growth period compared with the controls, with no change in plant growth. In tomato, the potassium content in the potassium-restricted group was also reduced to 50–89% of the control. There was no change in the fresh weight per fruit of the tomatoes; however, the total yield was reduced. In this chapter, we introduce the researches of the cultivation method for leafy vegetables and tomatoes with low potassium content while still maintaining normal plant growth. Furthermore, the changes of the contents in minerals, ascorbic acid, and sugar in low potassium vegetables were reported.

Keywords: ascorbic acid, dialysis patients, leafy vegetable, potassium, sodium, tomato, soil-less culture

1. Introduction

In the year 2010, the number of dialysis patients worldwide was approximately 2.16 million [1]. Because the symptoms of kidney disease are subtle, and one of the most significant primary diseases in kidney disease is diabetes, it is estimated that tens of thousands to several million people have a preliminary stage of kidney disease [2]; this suggests a further increase in dialysis patients. By 2030, this figure will project to more than double to 5.439 million, with the largest growth in Asia [1]. Because dialysis patients have dysfunctional potassium excretion mechanisms, there is a possibility of them suffering from serious electrocardiographic abnormalities and heart failure due to hyperkalemia [3]. Therefore, disturbances in plasma potassium concentration, most commonly hyperkalemia, remain a constant threat to the health of dialysis patients [4]. Potassium intake must be restricted in dialysis patients. Because the vegetables that we generally eat contain high levels of potassium [5], dialysis patients should not eat raw vegetables, they should have them boiled or leached in water to remove excess potassium [6, 7]. Although potassium content is partially reduced by these methods, the degree of reduction is limited. In addition, other important minerals and vitamins get eluted and disassembled by these methods. Furthermore, many dietary fibers are included in vegetables, but a dietary fiber becomes lacking in it because vegetables intake are limited as for the kidney disease dialysis patient. As a result, it is reported that the difference in dietary fiber intake of the chronic kidney disease patient (CKD) including the dialysis patient is related to the inflammatory reaction (C-reactivity protein) and death rate [8]. There are many disadvantages by limiting vegetables intake.

It is believed that vegetables cultivated to contain lower potassium levels are beneficial for dialysis patients as compared to those cultivated by the general method. The former allows patients to eat raw vegetables in moderation. The potassium content in these vegetables can be reduced even further by boiling or leaching in water.

On the other hand, potassium is an essential macronutrient for plant growth [9]. Potassium plays a significant physiological role in the metabolism of substances within a cell such as the maintenance of protoplasmic structure and pH levels [10], and the compatible solutes required for osmotic adjustment [11]. Therefore, it is expected that limited supply of potassium will inhibit plant growth. Therefore, it is important to investigate the amount to which the potassium levels can be reduced while still maintaining the optimum levels for plant growth.

The objective of this chapter is to introduce the researches of the cultivation method for leafy vegetables and tomatoes with low potassium content for dialysis patients who are restricted potassium intake, while still maintaining normal plant growth. Furthermore, the changes of the contents in minerals, ascorbic acid, and sugar in low potassium vegetables were reported.

2. Examination of the cultivation method of vegetables with low potassium content and changes of that quality

2.1. Examination of the cultivation method of the spinach with the low potassium content

Ogawa et al. [12] examined the effective cultivation method of the spinach (*Spinacia oleracea* L.), which had high potassium content. Spinach grown hydroponically received one of two treatments:

1. Cultivation with reduced potassium applications throughout the growth period.
2. Cultivation without potassium applications during the latter half of the growth period.

2.1.1. *Cultivation with reduced potassium applications throughout the growth period*

During the cultivation period, spinach was cultivated at potassium concentration of 1/2 (1/2 K treatment), 1/4 (1/4 K treatment), and 1/8 (1/8 K treatment) of the control. The influence that a difference of the potassium concentration in water culture medium gave the potassium content at the harvest (**Figure 1**). There was no significant difference in 1/2 K treatment and the 1/4 K treatment than control, but the potassium content significantly decreased in 1/8 K treatment. Potassium content was 7.97 mg per 1 g of fresh weight in the control, but it was 5.45 mg in the 1/8 K treatment, and it decreased by 32%.

Fresh weight, the number of leaves, water content, and the SPAD value, which shows chlorophyll content, in each treatment at the harvest are shown in **Table 1**. There was no significant difference at the time of a harvest in fresh weight and the number of leaves by the treatments that had lower potassium concentration than a control. The water content showed 94.0% in 1/2 K treatment and slightly increased compared with a control. However, there was not the significant difference in other treatment. The SPAD value was significantly lower in 1/2 K treatment than a control and was significantly high in 1/8 K treatment.

Table 2 shows the content of magnesium, calcium, sodium, sulfur, copper, iron, manganese, and zinc in the harvest. The content of the major element except sulfur increased by the treatment that had low potassium concentration. Sodium contents increased conspicuously. Sodium content was 828 μg per 1 g of fresh weight in the 1/8 K treatment, which had the lowest potassium concentration and was 12.7-fold of the control.

2.1.2. *Cultivation without potassium applications during the latter half of the growth period*

Spinach plants that were grown hydroponically received one of three treatments:

1. Treatment not to include potassium in water culture medium for 1 week before the harvest (1W0K treatment)

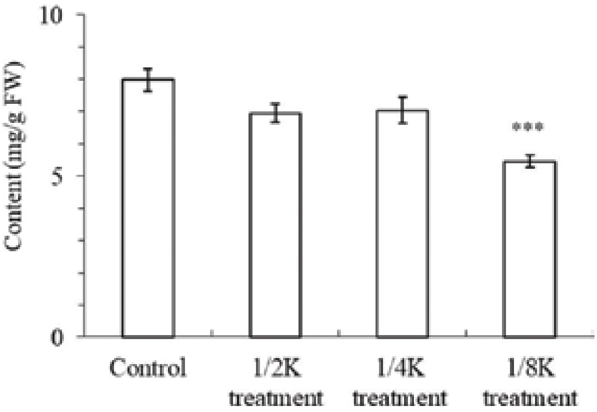

Figure 1. Changes in potassium contents at the harvest by the cultivation with reduced potassium applications throughout the growth period. Each value shows the mean ± standard error (n = 5). *** represents statistical significance at $p < 0.001$ compared with control by t-test. (From Ogawa et al. (12)).

	Control	1/2K treatment		1/4K treatment		1/8K treatment	
Fresh weight (g/plant)	15.1 ± 2.0	25.9 ± 4.7	NS	22.6 ± 4.6	NS	18.9 ± 3.2	NS
Leaf number par plant	14.4 ± 0.9	13.2 ± 1.1	NS	13.4 ± 1.6	NS	13.6 ± 1.0	NS
Water content (%)	92.9 ± 0.2	94.0 ± 0.2	**	93.4 ± 0.4	NS	93.2 ± 0.2	NS
SPAD value	43.5 ± 1.5	38.3 ± 0.6	**	42.0 ± 1.5	NS	48.0 ± 0.8	**

Each value shows the mean ± standard error (n = 5).

**Represents statistical significance at *p<0.01* compared with control. NS, not significant by *t*-test. (From Ogawa et al. [12]).

Table 1. Changes in fresh weight, leaf number, water content and SPAD value at the harvest by the cultivation with reduced potassium applications through the growth period.

	Control	1/2K treatment		1/4K treatment		1/8K treatment	
Calcium	331 ± 29.2	308 ± 23.7	NS	375 ± 30.6	NS	528 ± 44.9	**
Magnesium	371 ± 8.6	325 ± 18.9	NS	462 ± 28.9	*	465 ± 25.2	**
Sodium	65.2 ± 2.8	108 ± 6.5	***	648 ± 82.9	***	828 ± 57.1	***
Sulfur	337 ± 5.3	289 ± 10.4	**	356 ± 37.4	NS	340 ± 13.4	NS
Copper	0.5 ± 0.03	0.4 ± 0.02	**	0.4 ± 0.06	NS	0.4 ± 0.02	*
Iron	6.4 ± 0.19	4.7 ± 0.23	***	7.3 ± 1.14	NS	7.4 ± 0.51	NS
Manganese	13.5 ± 1.78	10.5 ± 0.50	NS	12.2 ± 1.90	NS	13.8 ± 0.84	NS
Zinc	4.5 ± 0.18	2.3 ± 0.13	***	3.5 ± 0.52	NS	3.4 ± 0.32	*

Each value shows the mean ± standard error (n = 5).

*, ** and *** represent statistical significance at *p<0.05, 0.01* and *0.001* compared with control, respectively. NS, not significant by *t*-test. (From Ogawa et al. [12]).

Table 2. Changes in mineral contents per fresh weight (μg/g FW) at the harvest by the cultivation with reduced potassium applications through the growth period.

2. Treatment to reduce potassium concentration to 1/4 of the control before 2 weeks of the harvest and not to include potassium before 1 week (1 W1/4 K treatment)
3. Treatment do not include potassium in water culture medium for 2 weeks before the harvest (2W0K treatment)

The potassium content significantly decreased in comparison with a control in each treatment (**Figure 2**). The potassium content was 4.79, 3.61, and 1.71 mg per 1 g of fresh weight in 1W0K treatment, 1 W1/4 K treatment, and 2W0K treatment, respectively. They had

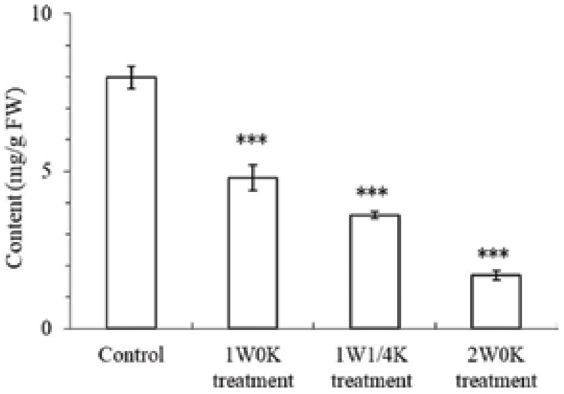

Figure 2. Changes in potassium contents at the harvest by the cultivation without potassium applications during the latter half of the growth period. Each value shows the mean ± standard error (n = 5). *** represents statistical significance at $p < 0.001$ compared with control by t-test. (From Ogawa et al. (12)).

lower 40, 55, and 79% than a control in 1W0K treatment, 1 W1/4 K treatment, and 2W0K treatment, respectively.

Fresh weight, the number of leaves, water content, and the SPAD value in each treatment at the harvest are shown in **Table 3**. There was no significant difference at the time of a harvest in fresh weight, the number of leaves, and the SPAD value by the low potassium treatments. The water content showed 94.3% in 1W0K treatment and slightly increased compared with a control. However, there was no significant difference than a control by other treatment.

Table 4 shows the content of magnesium, calcium, sodium, sulfur, copper, iron, manganese, and zinc in the harvest. The content of the major element except sulfur increased by the low potassium treatments. Sodium contents increased conspicuously. Sodium content was 1646 μg per 1 g of fresh weight in the 2W0K treatment, which had the lowest potassium concentration and was 25.3-fold of the control.

From these results, it was revealed that we could reduce potassium more effectively without inhibiting growth by the cultivation method with no potassium applications during the latter half of the growth period.

2.2. Adaptation of the cultivation method for other leafy vegetables

Using a result concerned with the spinach [12], cultivation to reduce potassium without inhibiting growth was investigated in red leaf lettuce (*Lactuca sativa* L. var. *crispa*), asparagus lettuce (*Lactuca sativa* L. var. *angustana*), and komatsuna (*Brassica rapa* L. var. *perviridis*) [13].

Table 5 shows the changes in the ion content in the three leafy vegetables at harvest for each treatment. The potassium contents of red leaf lettuce, asparagus lettuce, and komatsuna in the control group were 3634, 3709, and 4226 μg per 1 g of fresh weight, respectively, and those in the potassium-restricted group were 1026, 1545, and 1315 μg, respectively. These values

	Control	1W0K treatment		1W1/4K treatment		s2W0K treatment	
Fresh weight (g/plant)	15.1 ± 2.0	23.3 ± 5.3	NS	14.8 ± 2.5	NS	15.8 ± 2.3	NS
Leaf number par plant	14.4 ± 0.9	14.5 ± 1.4	NS	14.2 ± 1.2	NS	14.0 ± 0.3	NS
Water content (%)	92.9 ± 0.2	94.3 ± 0.2	**	93.3 ± 0.2	NS	93.1 ± 0.3	NS
SPAD value	43.5 ± 1.5	42.4 ± 1.2	NS	44.0 ± 1.2	NS	43.7 ± 1.3	NS

Each value shows the mean ± standard error (n = 5).

**represents statistical significance at $p<0.01$ compared with control. NS, not significant by *t*-test. (From Ogawa et al. [12])

Table 3. Changes in fresh weight, leaf number, water content and SPAD value at the harvest by the cultivation with no potassium applications after the halfway point of the growth period.

	Control	1W0K treatment		1W1/4K treatment		2W0K treatment	
Calcium	331 ± 29.2	566 ± 39.8	**	712 ± 68.2	***	767 ± 40.4	***
Magnesium	371 ± 8.6	408 ± 32.6	NS	424 ± 53.7	NS	475 ± 17.1	***
Sodium	65 ± 2.8	983 ± 26.5	***	1357 ± 35.8	***	1646 ± 124.7	***
Sulfur	337 ± 5.3	270 ± 23.7	*	300 ± 15.8	NS	348 ± 7.1	NS
Copper	0.5 ± 0.03	0.4 ± 0.03	**	0.5 ± 0.03	NS	0.5 ± 0.05	NS
Iron	6.4 ± 0.19	5.8 ± 0.93	NS	6.0 ± 0.52	NS	7.5 ± 0.24	**
Manganese	13.5 ± 1.78	12.6 ± 1.03	NS	13.8 ± 0.70	NS	19.1 ± 0.91	*
Zinc	4.5 ± 0.18	2.3 ± 0.21	***	2.1 ± 0.11	***	2.4 ± 0.06	***

Each value shows the mean ± standard error (n = 5).

*, ** and *** represent statistical significance at $p<0.05$, *0.01* and *0.001* compared with control, respectively. NS, not significant by *t*-test. (From Ogawa et al. [12]).

Table 4. Changes in mineral contents per fresh weight (μg/g FW) at the harvest by the cultivation with no potassium applications after the halfway point of the growth period.

	Red leaf lettuce			Asparagus lettuce			Komatsuna		
	Control	Potassium restricted		Control	Potassium restricted		Control	Potassium restricted	
Potassium	3634 ± 146	1026 ± 48	*	3709 ± 230	1545 ± 90	*	4226 ± 192	1315 ± 36	*
Calcium	373 ± 17	364 ± 12	NS	316 ± 20	287 ± 11	NS	1349 ± 71	1406 ± 59	NS
Magnesium	375 ± 15	492 ± 15	*	206 ± 13	299 ± 12	*	377 ± 24	416 ± 20	NS
Sodium	77 ± 11	1031 ± 55	*	38 ± 2	477 ± 37	*	139 ± 11	1692 ± 60	*

Each value shows the mean ± standard error (n = 8).

*Represents statistical significance at $p<0.05$ compared with control. NS, not significant by *t*-test. (From Ogawa et al. [13])

Table 5. Changes in potassium, calcium, magnesium and sodium contents (μg/g FW) of red leaf lettuce, asparagus lettuce and komatsuna at the harvest as affected by potassium-restricted treatment.

represent a significant reduction in potassium levels: 28, 42, and 31% of the control, respectively. The sodium content in all plants and the magnesium contents in the red leaf lettuce and asparagus lettuce were increased significantly when the potassium supply was restricted. Particularly, the sodium content was markedly increased. The sodium contents in red leaf lettuce, asparagus lettuce, and komatsuna in the control group were 77, 38, and 139 μg per 1 g of fresh weight, respectively, while those in the potassium-restricted group were 1031, 477, and 1692 μg, respectively. This represents a 13.4-fold, a 12.6-fold, and a 12.2-fold, respectively, increase as compared with the control group.

Table 6 shows fresh weight, dry weight, and water content at harvest for each treatment group. For all plants, there was no significant difference in these measurements as compared with the control group. These results showed that there was no change in the plant growth, despite the potassium restriction.

Despite the reduction of potassium supply, plant growth was maintained and some other ion contents were increased. One of the roles of potassium ion is to adjust osmotic potential. Therefore, the number of moles of potassium, sodium, magnesium, and calcium ions per fresh weight was calculated to show the total number of moles of these ions (**Figure 3**). The number of moles of sodium and magnesium ions was greater in the potassium-restricted group for all plants. However, the total number of moles in the potassium-restricted group was 83 and 71% of that of the control group in red leaf lettuce and asparagus lettuce, respectively. For komatsuna, the total number of moles in the potassium-restricted group was 98% of that of the control group.

2.3. Examination of the cultivation method of the tomato with low potassium content

Tomatoes (*Solanum lycopersicum* L.) were grown hydroponically under two different potassium-restricted treatments [13].

1. Treatment not to include potassium in water culture medium after the first fruit developed at the first truss (0 K treatment).

	Red leaf lettuce			**Asparagus lettuce**			**Komatsuna**		
	Control	**Potassium restricted**		**Control**	**Potassium restricted**		**Control**	**Potassium restricted**	
Fresh weight (g)	53.9 ± 4.1	50.3 ± 4.3	NS	39.8 ± 4.6	40.6 ± 3.2	NS	176.1 ± 22.0	178.4 ± 11.1	NS
Dry weight (g)	3.4 ± 0.2	3.1 ± 0.3	NS	1.7 ± 0.3	1.6 ± 0.2	NS	10.4 ± 1.5	10.2 ± 0.6	NS
Water content (%)	93.7 ± 0.2	93.8 ± 0.2	NS	95.7 ± 0.2	96.0 ± 0.2	NS	94.1 ± 0.2	94.3 ± 0.2	NS

Each value shows the mean ± standard error (n = 8).

NS, not significant compared with control by *t*-test. (From Ogawa et al. [13])

Table 6. Changes in fresh weight, dry weight and water content of red leaf lettuce, asparagus lettuce and komatsuna at the harvest as affected by potassium restricted treatment.

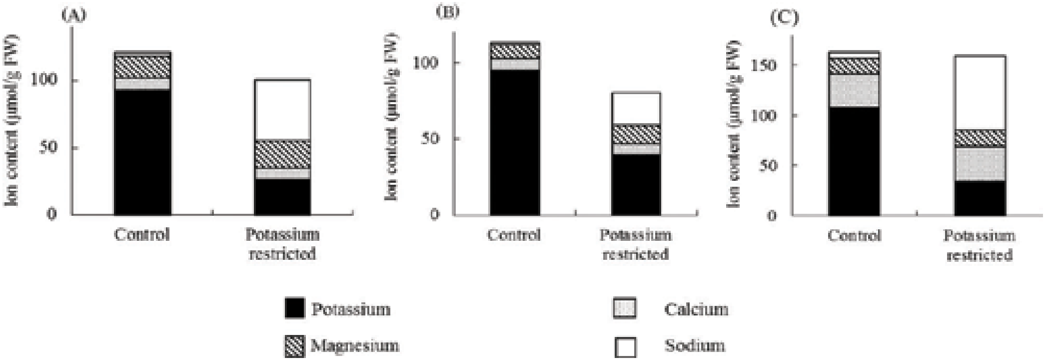

Figure 3. Changes in total ion contents of potassium, calcium, magnesium, and sodium in red leaf lettuce (A), asparagus lettuce (B) and komatsuna (C) at the harvest as affected by potassium-restricted treatment. (from Ogawa et al. [13]).

2. Treatment in a water culture medium alternated every week with and without potassium after the first fruit developed at the first truss (1W0K treatment).

Table 7 shows the changes in ion content in tomatoes at harvest in each treatment group. The potassium contents in the potassium-restricted groups (1W0K and 0 K treatments) in all trusses were reduced significantly when compared with the control. The potassium content of the control group was 1551–2126 μg per 1 g of fresh weight in each truss. On the other hand, the potassium contents were 1382–1645 μg in the 1W0K treatment group and 790–1335 μg in the 0 K treatment group. The percentages were 74–89% and 45–73% of the control group for the 1W0K and 0 K treatment groups. In the fifth truss of the 0 K treatment group, no fruit was harvested by the growth inhibition due to the potassium-restricted treatment.

Calcium and magnesium content was affected slightly by the treatment with potassium restriction (**Table 7**). The calcium content was significantly higher than that in the control group in the third truss of 1W0K treatment and in the first truss of 0 K treatment. The magnesium content was significantly higher than that in the control group in the fifth truss of 1W0K treatment and in the first and the second trusses of 0 K treatment. On the other hand, the sodium content was drastically increased by the treatment with potassium restriction. The sodium contents were 60–106 μg in the 1W0K treatment group and 88–179 μg in the 0 K treatment group. The percentages were 128–200% and 187–332% of the control group in the 1W0K and 0 K treatment groups.

Fresh weight of fruits and the total number of fruits harvested were not affected significantly by the two treatments with potassium restriction, except for the fourth and the fifth truss of the 0 K treatment group (**Table 7**). In the fourth truss of the 0 K treatment group, fresh weight and the total number of fruit were significantly lower than that in the control group. In the 1W0K treatment group, the fresh weight in the fourth truss and the number of fruits in the second truss were higher than that in the control group. Overall, the total fruit yield was not significantly changed by the two treatments with potassium restriction, except for the fourth and the fifth trusses in the 0 K treatment group.

Soluble solids content and water content were affected by the treatment with potassium restriction (**Table 7**). Compared to that in the control group, the soluble solids content was

	Truss	**1st**		**2nd**		**3rd**		**4th**		**5th**	
Fresh weight (g/fruit)	Control	39.9 ± 1.7	a	40.8 ± 2.0	a	44.3 ± 2.1	a	45.5 ± 2.0	b	46.3 ± 2.0	a
	1W0K	39.5 ± 2.1	a	42.7 ± 1.7	a	50.3 ± 1.7	a	49.8 ± 2.0	a	51.5 ± 1.8	a
	0K	42.7 ± 1.8	a	43.6 ± 2.4	a	48.5 ± 3.2	a	34.9 ± 2.7	c		
Number of fruit	Control	13.0 ± 1.5	a	13.0 ± 1.0	a	11.7 ± 0.9	a	13.3 ± 1.8	a	9.3 ± 0.7	a
	1W0K	11.3 ± 0.3	a	16.7 ± 0.3	b	12.7 ± 0.7	a	10.0 ± 1.0	ab	9.3 ± 0.9	a
	0K	10.7 ± 0.7	a	10.7 ± 0.3	a	7.0 ± 2.0	a	5.3 ± 0.9	b		
Soluble Solids Content (%)	Control	6.9 ± 0.1	a	6.6 ± 0.1	a	6.5 ± 0.1	a	6.2 ± 0.1	a	5.6 ± 0.1	a
	1W0K	6.7 ± 0.1	a	6.4 ± 0.1	a	6.2 ± 0.1	a	5.5 ± 0.1	b	5.2 ± 0.1	b
	0K	6.7 ± 0.1	a	6.6 ± 0.1	a	5.8 ± 0.2	b	4.9 ± 0.3	c		
Potassium (μg/g FW)	Control	1825 ± 35.0	a	2013 ± 57.3	a	2126 ± 77.9	a	1747 ± 37.7	a	1551 ± 22.6	a
	1W0K	1429 ± 26.2	b	1489 ± 27.2	b	1645 ± 48.1	b	1458 ± 39.7	b	1382 ± 22.7	b
	0K	1335 ± 26.5	b	1155 ± 33.2	c	1072 ± 48.2	c	790 ± 47.5	c		
Calcium (μg/g FW)	Control	36.8 ± 3.5	b	59.0 ± 16.2	ab	58.1 ± 7.0	b	74.4 ± 4.4	a	61.3 ± 3.7	a
	1W0K	47.9 ± 3.9	b	53.1 ± 7.7	b	107.9 ± 5.0	a	84.3 ± 3.8	a	64.0 ± 5.7	a
	0K	61.8 ± 3.4	a	95.7 ± 9.2	a	80.6 ± 6.7	b	90.0 ± 8.3	a		
Magnesium (μg/g FW)	Control	75.1 ± 2.7	b	97.5 ± 2.7	b	100.8 ± 3.2	a	98.7 ± 3.5	a	89.0 ± 2.2	b
	1W0K	77.4 ± 3.1	ab	95.4 ± 2.2	b	107.2 ± 2.5	a	96.7 ± 2.0	a	96.9 ± 2.2	a
	0K	84.8 ± 2.3	a	111.9 ± 2.7	a	109.5 ± 4.5	a	95.1 ± 4.9	a		
Sodium (μg/g FW)	Control	46.9 ± 5.6	b	34.6 ± 9.6	c	57.3 ± 5.6	c	75.3 ± 3.2	c	16.9 ± 2.2	b
	1W0K	59.9 ± 3.5	b	69.4 ± 3.8	b	99.5 ± 8.6	b	106.3 ± 4.4	b	32.3 ± 2.3	a
	0K	87.5 ± 6.7	a	114.9 ± 4.5	a	179.0 ± 11.5	a	160.3 ± 13.0	a		

Each value shows the mean ± standard error. Means followed by the common letters under each trust were not significantly different according to the multiple test of Tukey (*$p<0.05$*). In the 5th truss of 0K treatment, no fruit were harvested. (From Ogawa et al. [13])

Table 7. Changes in fresh weight, number of fruit, soluble solids content and the contents of potassium calcium, magnesium and sodium contents of tomato at the harvest as affected by potassium-restricted treatment.

significantly lower in the fourth and the fifth trusses of the 1W0K treatment group and in the third and the fourth trusses of the 0 K treatment group. Water content was significantly higher than that in the control in the second to the fifth trusses of the 1W0K treatment group and in the second to the fourth trusses of the 0 K treatment group.

2.4. Elucidation of a change of the ascorbic acid content under the low potassium condition and the mechanism

Ogawa et al. [14] hypothesized that a higher ascorbic acid content results when glucose content, in the form of an ascorbate matrix, increases in a plant. It has been suggested that glucose content increases by osmoregulation when lettuce and spinach are grown hydroponically

	Red leaf lettuce			**Asparagus lettuce**			**Komatsuna**			**Spinach**		
	Control	**Potassium restricted**		**Control**	**Potassium restricted**		**Control**	**Potassium restricted**		**Control**	**Potassium restricted**	
Vitamin C content (μmol/g FW)	1.05 ± 0.31	0.94 ± 0.22	NS	0.20 ± 0.03	0.38 ± 0.04	*	0.29 ± 0.04	0.44 ± 0.02	*	0.80 ± 0.12	1.16 ± 0.10	*
Glucose content (μmol/g FW)	10.01 ± 1.31	39.86 ± 6.26	**	6.02 ± 1.39	5.75 ± 1.24	NS	3.29 ± 0.44	5.58 ± 0.85	*	2.96 ± 0.23	8.28 ± 1.46	**
GLDH activity (nmol/min mg protein)	49.10 ± 4.26	40.70 ± 6.40	NS	32.56 ± 5.39	25.98 ± 5.66	NS	13.74 ± 3.01	30.25 ± 4.49	*	17.88 ± 1.87	32.54 ± 4.36	*

Each value shows the mean ± standard error (n = 5).

* and ** represent statistical significance at *p<0.05* and *0.01* compared with control, respectively. NS, not significant by *t*-test. (From Ogawa et al. [14])

Table 8. Changes in vitamin C content, glucose content and GLDH activity of red leaf lettuce, green leaf lettuce, frilly lettuce and spinach at the harvest as affected by potassium-restricted treatment.

without potassium during the latter half of their growth period. The relationship among ascorbic acid content, glucose content, and the activity of L-galactono-γ-lactone dehydrogenase (EC 1.3.2.3; GLDH) was investigated in red leaf lettuce (*Lactuca sativa* L.), green leaf lettuce (*Lactuca sativa* L.), frilly lettuce (*Lactuca sativa* L.), and spinach (*Spinacia oleracea* L.) by using a cultivation method that involves potassium restriction [14].

In frilly lettuce, the ascorbic acid level with potassium restriction treatment was 1.5 times higher than that in the control (**Table 8**). At this time, glucose content and the GLDH activity with potassium restriction treatment were 1.7 and 2.2 times higher than those in the control, respectively. Similarly, in spinach, ascorbic acid content, glucose content, and GLDH activity with potassium restriction treatment were 1.4, 2.4, and 1.8 times higher than those in the control, respectively. In green lettuce, the ascorbic acid level with potassium restriction treatment was 1.5 times higher than that in the control, although glucose content and GLDH activity did not change. In red leaf lettuce, ascorbic acid content and GLDH activity did not change with potassium restriction treatment, although glucose content increased significantly.

3. Discussion

Potassium content was successfully reduced in leafy vegetables, with no significant change in fresh weight when using the hydroponic method in which potassium was applied in the early period and not applied during the last 7–10 days before harvest (**Figure 2** and **Table 5**). The potassium content for the "no potassium" group was 30–40% of the control group. Furthermore, the potassium content in tomato was reduced significantly by the 1W0K and 0 K treatments with no decrease in fresh weight per fruit (**Table 7**). It was reported that despite the presence of very low potassium concentrations in the culture medium, the amount of potassium in the plant tissues was sufficient to sustain the plant vegetative growth [15].

The total fruit yield of tomatoes decreased in the upper truss of the 0 K treatment group. The soluble solids content was decreased significantly, and the water content was increased significantly in the upper truss of the "no potassium" group (**Table 7**). It has been reported that potassium deficiency can reduce stomatal aperture, thereby impairing CO_2 fixation, disrupting the conversion of light energy to chemical energy, and the phloem export of photosynthates from the source to sink organs [16]. It was believed that we should use the technique by the low node-order pinching and high-density planting when you cultivated a low potassium tomato.

When potassium content was reduced drastically, sodium and magnesium contents were increased significantly in leafy vegetables (**Tables 2**, **4**, and **5**) and tomatoes (**Table 7**). It is suggested that the increments of these ions compensated for the potassium reduction. The presence of sodium and magnesium ions is important in alleviating the effects of potassium deficiency. It is suggested that the increase in sodium and magnesium concentrations occurred in response to the decrease in potassium [17, 18]. Potassium ions and magnesium ions have similar roles in osmotic adjustment, enzyme activation, and cellular pH control [19]. It was reported that the absorption of magnesium was increased when the amount of potassium fertilization was reduced in soybeans [20]. Sodium ions could replace potassium ion in nonspecific physiological and biochemical functions [21]. It was reported that substituting 20% NaCl for 20% KCl showed no significant effects on plant growth in spinach grown in sand culture [22]. In this study, the total number of moles in potassium-restricted treatments was lower than those in control, and the decline in potassium ions was not explained sufficiently by the increase in the other three ions in red leaf lettuce, asparagus lettuce (**Figure 3**), and tomato (data not shown). It was reported that other solutes, for example sugars and amino acids, contribute to osmotic adjustment [11]. It is considered that the absence of normal potassium levels resulted in an increase in the concentration of these solutes.

The concentration of sodium increased with the reduction in potassium concentration. An increase in sodium intake is not advisable for dialysis patients because it leads to hyperpiesia and edema. It is necessary to evaluate the benefits of the reduction of potassium against the risks of the increase of sodium intake for dialysis patients whose potassium intake should be restricted to 1500–2000 mg per day [23] and NaCl (equivalent to 2000–3200 mg sodium) intake should be restricted 5000–8000 mg per day. Therefore, sodium intake must be limited to 1.3–1.6-fold of potassium intake. The potassium content per 1 g fresh weight of spinach, red leaf lettuce, asparagus lettuce, and komatsuna in the potassium-restricted groups reduced by 6.26, 2.90, 2.17, and 2.69 mg compared with the control group, respectively (**Figure 2** and **Table 5**), while the sodium contents increased by 1.58, 0.95, 0.44, and 1.66 mg, respectively (**Tables 4** and **5**). Therefore, the reduction of potassium was greater than the increase in sodium in each plant. In addition, potassium intake can only be determined by a patient's diet. Consequently, eating food with low potassium content is an effective way to limit the potassium intake. On the other hand, limiting the amount of salt used is a more effective way of reducing sodium intake than concentrating only on eating foods with low sodium content. We conclude that the benefits of reducing the intake of potassium are greater than the risks of increasing the intake of sodium.

The increase in glucose content in frilly lettuce and spinach for osmoregulation during potassium restriction treatment supports our hypothesis and resulted in elevated ascorbic acid levels (**Table 8**). A significant association between glucose content and ascorbic acid content in tomato under a salt stress condition has been previously reported [24]. It was reported that exogenous glucose treatment increased the ascorbic acid content in rice roots [25]. The increase in ascorbic acid content by potassium restriction was accompanied by an increase in GHLD activity (**Table 8**). Previous studies showed that ascorbic acid accumulates when GHDL is upregulated [26, 27]. Therefore, the increase in ascorbic acid content observed in this study may be attributable to the accumulation of the ascorbate matrix and the upregulation of GHDL during potassium restriction.

Glucose content and GLDH activity did not change with potassium restriction in green lettuce, although the level of ascorbic acid increased (**Table 8**). These findings suggest that an indicator induced an increase in the level of metabolites from glucose to ascorbic acid. It was reported that ascorbic acid content increased when exogenous galactonolactone was introduced [25]. In wheat, ascorbic acid contents change without increasing its GHDL activity [28]. These results support the results that ascorbic acid content increased without changes in glucose levels and GLDH activity.

Glucose content increased with potassium restriction in red reef lettuce, although GLDH activity and ascorbic acid content remained the same. These results suggest that glucose is also used by other metabolic systems such as the glycolytic pathway and the synthesis pathways for cellulose and starch.

4. Conclusion

In this chapter, the author demonstrated a cultivation method to reduce the potassium content in leafy vegetables without causing significant potassium deficiency symptoms. Potassium content was also successfully reduced in tomatoes, with no significant change in the fresh weight per fruit, although the total yield was reduced. Furthermore, the author showed the changes of minerals and the ascorbic acid content and the mechanism. These results will contribute to an improvement in the dietary quality of dialysis patients.

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Chapter 6

Software for Calculation of Nutrient Solution for Fruits and Leafy Vegetables in NFT Hydroponic System

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Additional information is available at the end of the chapter

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Abstract

Information technology is present in virtually all areas of science as a productivity tool, assisting professionals in these areas in their daily work. In this sense, the objective of the research was the development of a free software for use over the Internet, with a friendly interface and intuitive navigation, for calculation of nutrient solution for fruit vegetables and leaves in hydroponic NFT system. To develop the software, we used the technologies PHP5 (Programming Language), MYSQL (Database), CSS5 (Style Language), HTML5 (Markup Language) and CodeIgniter (Framework). The software has among its functions the user registration, calculation of the nutrient solution and the issuance of reports in PDF format. Calculation of the nutrient solution is available for various crops. The calculation proposes the quantity of different fertilizers needed to prepare the nutrient solution for the chosen hydroponic crops. Two software known as Hidrosolun and Hidrosical (registration number BR 51201400613–1 and BR 51201400614–0) were created and registered at the National Institute of Industrial Property (INPI), a federal agency responsible for the registration of intellectual property rights for the industry. The software developed is easy to use, without the need to install hardware with high configurations.

Keywords: plant nutrition, soil solution, information technology, hydroponics, solution management

1. Introduction

The importance of agriculture in the lives of human beings is undeniable and is a fundamental activity for the survival of civilization. Brazil stands out as one of the world's great producers in the area of olericulture, due to its great territorial area, favorable climate, with soil of easy handling and availability of abundant water. Among the various techniques of plant cultivation, hydroponics is the technique of growing plants without soil, where the roots develop in balanced nutrient solution, with all the nutrients essential to the development of the plant, being a technique of cultivation in economically protected environments feasible and environmentally sound. Proper plant nutrition also increases crop tolerance to pest and disease attack.

For the success of the hydroponic cultivation, it is necessary to develop adequate computational tools that will assist the producer in the calculation of the correct dosages of the solutions, since there are many crops to be considered, as well as a large amount of inputs for fertilization.

A computerized system to calculate the hydroponic solution allows to offer more accurate and fast results. Using software, the grower who grows in a hydroponic system will have a better facility to calculate the correct dosage of nutrients, obtaining more satisfactory results with a lower cost. In this context, accessing tools via the Internet makes it easier to use programs, regardless of geographical location, and there is no need to install programs on personal computers.

In this sense, the objective of the research was the development of a free software for use over the Internet, with a friendly interface and intuitive navigation, for calculation of nutrient solution for fruit vegetables and leaves in hydroponic NFT system.

2. Hydroponic system cultivation

According to Embrapa [1], protected cultivation allows farmers to offer the market products with good visual quality in periods of low supply and high prices, contributing to a good profitability, which justifies the investment with the protected structures. Brazil has more than 30,000 hectares of protected cultivation, being the country with the largest cultivated area in this system, in South America.

Protected cultivation, which has the potential to double the productivity reached in the open field, emerges as a technique capable of reconciling high yields with quality in environmental conditions that are potentially stressful to plants and may compromise the production of vegetables. In the last two decades, the protected crop, worldwide, increased 400%, from 700,000 to 3.7 million hectares. The use of hydroponics in protected crops has been used as a tool to solve a wide range of problems, including the reduction of soil and groundwater contamination, and the nutritional biofortification of olive trees [2].

Among the several hydroponic systems that do not use substrates, "Nutrient Film Technique-NFT" is the most widespread in Brazil and in the world [3]. This technique favors the continuous or intermittent circulation of the nutrient solution in culture channels, which can be varied in size and made by different materials, being the most common PVC, polyethylene, polypropylene and masonry [4]. In this agricultural production system, there is still a need for the development of new technologies, notably the need for new software to assist the producer in calculating the nutrient solution [5], since the correct calculation of the nutrient solution is fundamental for success in production. The supply of nutrients at levels suitable for growth, minimizing production losses and providing better quality to fruit vegetables [6]. With the use and advancement of information technologies in the development of software for the Internet, IT stands out as a cross-cutting area for all sectors, gaining its space in agriculture, increasing competitiveness and optimizing production [7].

Hydroponics is an off-the-ground crop technology that promotes the diversification of activities related to agribusiness, as it generates a differentiated product of good quality and of great acceptance in the market, although it cannot be certified As organic cultivation, since hydroponics is not a natural method of cultivation [8, 9]. It is a technique of cultivation in protected environment, in which the soil is replaced by the nutrient solution, in which are contained all the nutrients essential to the development of the plants [10].

Hydroponics has been growing substantially in Brazil, driven by the demand of the consumer market for differentiated vegetables, as well as the higher value added to the product, thus generating significant growth in the hydroponic cultivation of fruit and leafy vegetables [3]. This technique has many advantages over traditional soil cultivation, as it eliminates traditional agricultural operations, such as requiring less human effort, lack of competition for plants for nutrients and water, significant increase in productivity, precocity in the harvest and less occurrence of phytosanitary problems, with less application of pesticides, which generates a better final product quality [11].

3. Hydroponic cultivation system: NFT

In Brazil, the hydroponic crop is predominantly made by the NFT system. Many of these hydroponic crops are not successful, mainly due to the lack of knowledge of the formulation and the adequate management of nutrient solutions [12].

In the NFT system, the plants grow having their root system in a channel through which the nutrient solution circulates. The pioneer of this technique was Allen Cooper, at the Glasshouse Crop Research Institute, Littlehampton, England, in 1965, who determined that the thickness of the flow of the nutrient solution passing through the roots of the plants should be small (laminar) in such a way that the roots are not completely submerged, lacking the necessary oxygen [13]. In this system, there is no need to place any material inside the channels, such as stones, sand, expanded clay and burnt rice straw, and the canals contain only the roots of the plants and the nutrient solution. The nutrient solution is stored in a reservoir, from where it is repressed to the top of the cultivation bed (bench), passing through the channels, being collected at the bottom of the bed, to return to the tank [14].

3.1. Mineral nutrition of plants

One of the basic principles for plant production, in both soil and nonsoil cultivation systems, (hydroponics) is to provide all the nutrients the plant needs. If there is a nutrient imbalance in the environment in which the plant grows, the production will be reduced, hence the need to supply all the elements that the plants need, in the correct dose, according to the requirements of each crop [15].

Several chemical elements are essential for the development of plants, which are presented in **Table 1**.

These elements can be classified according to their origin in:

- Nonmineral macronutrients: C, H, O;
- Mineral macronutrients: N, P, K, Ca, Mg, S;
- Micronutrients: Mn, Fe, B, Zn, Cu, Mo, Cl.

The division between macronutrients and micronutrients takes into account only the amount that the plant absorbs from each nutrient to complete its productive cycle. The plants have about 90–95% of their weight in C, H, O, which are elements that come from air and water, and are abundant in nature. Therefore, in the nutrient solution, the emphasis is on the mineral elements [10].

Carbon	**C**	**Magnesium**	**Mg**
Hydrogen	H	Manganese	Mn
Oxygen	O	Iron	Fe
Nitrogen	N	Zinc	Zn
Phosphor	P	Boron	B
Potassium	K	Copper	Cu
Sulfur	S	Molybdenum	Mo
Calcium	Ca	Chlorine	Cl

Table 1. Chemical elements used in the production of plants.

Fertilizers	**Molecular formula**	**N**	**P**	**K**	**Ca**	**Mg**	**S**
		%					
Potassium nitrate	KNO_3	14	—	36.5	—	—	—
Sodium and potassium nitrate	$NaNO_3$	13	—	11.6	—	—	—
Ammonium nitrate	NH_4NO_3	34	—	—	—	—	—
Calcium nitrate	$Ca(NO_3)_2$	15	—	—	20	—	—
Nitrocalcium	NH_4NO_3 + limestone	22	—	—	7	—	—
Monoammonium phosphate	$NH_4H_2PO_4$	10	21.1	—	—	—	—
Diammonium phosphate	$(NH_4)_2HPO_4$	18	20.2	—	—	—	—
Urea	$(NH_2)_2CO$	45	—	—	—	—	—
Ammonium sulfate	$(NH_4)_2SO_4$	20	—	—	—	—	24
Potassium phosphate	KH_2PO_4	—	24	31	—	—	—
Potassium chloride	KCl	—	—	49.8	—	—	—
Potassium sulfate	K_2SO_4	—	—	41.5	—	—	17
Magnesium sulfate	$MgSO_4$	—	—	—	—	9.5	13

Table 2. Composition of some fertilizers used in hydroponics (macronutrients) [14].

3.2. Water as an essential element in hydroponics

In soilless cultivation, water quality is essential, as it will dissolve the essential elements that will nourish the plants. The water used must be potable and may be from artesian wells, water courses or rainfall collection [13]. In hydroponics, all nutrients are supplied to the plants in the solution that is prepared with different fertilizers. There are several salts that provide the same nutrients for plants; one should opt for those that are easier to dissolve in water, inexpensive and easily found in the trade. **Table 2** presents some of the most used fertilizers in hydroponics.

3.3. Suggestions for nutritional solutions

Tables 3–6 present nutritional solutions for the cultivation of tomato, cucumber and lettuce. The difference between solution A and solution B is in the amount of calcium nitrate used. Solution A is used in the growing phase of the plant and solution B is used in the fruiting phase. For the formation of the fruits, there is a greater absorption of calcium and nitrogen by the plants, a greater quantity of these nutrients being necessary in that phase.

Fertilizers	**Molecular formula**	**Nutrients**	**Tomato**		**Cucumber**	
			Solution A	**Solution B**	**Solution A**	**Solution B**
			g 1000 L			
Potassium nitrate	KNO_3	N. K	200	200	200	200
Magnesium sulfate	$MgSO_4$	Mg, S	500	500	500	500
Potassium phosphate	KH_2PO_4	K, P	270	270	270	270
Potassium sulfate	K_2SO_4	K, S	100	100	—	—
Calcium nitrate	$Ca(NO_3)_2$	N, Ca	500	680	680	1.357
Iron	Fe (chelated)	Fe	25	25	25	25
Micronutrients	Micronutrients	—	150 mL	150 mL	150 mL	150 mL

Table 3. Composition of nutritive solutions for tomato and cucumber [13].

Fertilizers	**Molecular formula**	**Nutrients**	**g 1000 L**
Boric acid	H_3BO_3	B	7.50
Magnesium sulfate	$MnCl_2\ 4H_2O$	Mn	6.75
Cupric chloride	$CuCl_{2+}2H_2O$	Cu	0.37
Ammonium molybdate	$(NH_4)_6\ MO_7O_{24}\ 4H_2O$	Mo	0.15
Zinc sulfate heptahydrate	$ZnSO_4\ 7H_2O$	Zn	1.18

Table 4. Preparation of solution containing micronutrients [13].

Fertilizer	Formula molecular	g / 1000 L
Calcium nitrate	$Ca(NO_3)_2$	1000
Potassium nitrate	KNO_3	600
Potassium chloride	KCl	150
Monoammonium phosphate	$NH_4H_2PO_4$	150
Magnesium sulfate	$MgSO_4$	250
Micronutrient solution	—	500 mL
Fe-EDTA solution	—	500 mL
Chlorine	Cl	100
Boric acid	H_3BO_3	20
Iron	Fe (chelated)	100
Magnesium sulfate	$MnCl_2\ 4H_2O$	50
Zinc sulfate heptahydrate	$ZnSO_4\ 7H_2O$	20
Cupric chloride	$CuCl_{2+}2H_2O$	6
Ammonium molybdate	$(NH_4)_6\ MO_7O_{24}\ 4H_2O$	0.1

Table 5. Nutrient solution composition for lettuce cultivation [10].

These quantities are used to prepare 450 mL stock solution. Hot water should be used to dissolve fertilizers well. Use 150 mL of the micronutrient-containing solution per 1000 L of culture solution.

In order to be efficiently absorbed by the roots, the iron must be chelated, so a solution containing 10 mg/mL of Fe must be prepared, to dissolve separately in each 450 mL of water, 50 g of ferrous

Product		(g/1000 L)
Calcium nitrate	$Ca(NO_3)_2$	750
Potassium nitrate	KNO_3	500
Phosphate monoammonium	$NH_4H_2PO_4$	150
Magnesium sulfate	$MgSO_4$	400
Copper sulfate	$CuCl_{2+}2H_2O$	0.15
Zinc sulfate	$ZnSO_4\ 7H_2O$	0.5
Manganese sulfate	$MnCl_2\ 4H_2O$	1.5
Boric acid	H_3BO_3	2.3
Ammonium molybdate	$(NH_4)_6\ MO_7O_{24}\ 4\ H_2O$	0.15
Tenso-Fe®	FeEDDHMA-6% Fe	30
Dissolvine®	FeEDTA-13% Fe	13.8
Ferrilene®	FeEDDHa-6% Fe	30
$FeEDTANa_2$ (10 mg mL Fe)	$FeEDTANa_2$	180 mL

Table 6. Quantities of salts for the preparation of nutrient solution [10].

Culture	N-$NO^-{}_3$	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
	(mg L^{-1})											
Lettuce	238	62	426	161	24	32	0.3	0.05	5	0.4	0.05	0.3
Tomato	169	62	311	153	43	50	0.2	0.03	4.3	1.1	0.05	0.3
Chili	152	39	245	110	29	32	0.3	0.03	3.7	0.4	0.05	0.3
Eggplant	179	46	303	127	39	48	0.3	0.05	3.2	0.6	0.05	0.3
Cucumber	174	56	258	153	41	54	0.2	0.03	4.3	1.1	0.05	0.3
Melon	170	39	225	153	24	32	0.2	0.03	2.2	0.6	0.05	0.3
Strawberry	125	46	176	119	24	32	0.2	0.03	2.5	0.4	0.05	0.3

Table 7. Values for nutrient solutions by the NFT system [16].

sulfate and 60 g of disodium EDTA. After dissolution, add EDTA to the ferrous sulfate solution. Make the air bubble in the solution obtained until complete dissolution of any precipitate formed. Store in a dark bottle and protect from light. If the producer prefers, he may purchase commercial products to be used as a nutrient solution for hydroponic cultivation, intended for various leafy vegetables and already used by many producers on a commercial scale.

In their preparation, the amounts of fertilizers are used, as shown in **Table 6**.

Table 7 presents suggestions for the preparation of nutrient solutions in the NFT system for different types of hardwood vegetables.

4. Calculation of nutrient solution

The calculation of the nutrient solution is done in a simplified way, dividing the fertilizers by nutrients, taking as starting point the fertilizers containing nitrate (NO^{-3}) in its formulation, such as calcium nitrate and potassium nitrate, if the formula:

$$F1 = \frac{100 \times \text{nutrient}}{\text{concentration}}(\%) \tag{1}$$

For each 100g of the fertilizer chosen, it is multiplied by the recommended amount of nutrient in the solution, which in this first stage can be calcium (Ca) or potassium (K), and then divided by the concentration of Ca or K in the fertilizer, thus obtaining the amount of fertilizer chosen.

Generally, the fertilizer used contains other nutrients necessary for the crop, making it necessary the calculation for its use, using the following formula for the calculation.

The value of F1 is the amount obtained in formula (1), which stipulates the amount of fertilizer to supply Ca or K, multiplied by the concentration (%) of the other nutrient in the fertilizer, divided by 100, which corresponds to 100 g.

Once the result of F2 is obtained, if this result is lower than the recommended amount for the crop, the process will be redone, starting with F1, using another fertilizer.

In a second step, the fertilizers containing potassium (K) are used, such as potassium phosphate monobasic, potassium chloride (white) or potassium sulfate. After choosing the fertilizer, it must be checked if there is potassium leftover from the first calculation, and if this happens, the following formula should be used:

If there is no "leftover," this formula is used in the same way as previously used, based on the fertilizer chosen.

This is done until all the macronutrients are calculated by calculating the recommended amounts for each crop.

In a final step of the calculation, not visible to the user, the calculations are made using the micronutrient contents of the fertilizers: boric acid, copper sulfate, manganese sulfate, zinc sulfate, sodium molybdate and ferrous sulfate. To calculate the macronutrients, the formula (1) is used.

Finally, the results are converted to the capacity of the chosen tank, and for 1000 L, the results are multiplied by 1, if they are 2000 L, the results are multiplied by 2, so successively up to the maximum value of 5000 L.

Next, a report is presented, which can be converted to PDF format for print, and the PHP library, mPDF that converts HTML to PDF, was used for this task. The report contains:

Fertilizers: option where all the fertilizers used to calculate nutrient solutions are visualized.

In the "Help" section, you can find the following options: Tutorial, where you can access a tutorial explaining the steps to create a solution and calculate it and get information to contact the system developers, as well as the tools used.

In the current version of the system, there is an administrative area, where it is possible to measure the number of users registered, where the "Administrators" group that associates with the user was added, restricting access to this area only to users belonging to this group. With the option "User Report," the name of the users with a totalizer is listed, leaving the structure open for more options for this area.

5. Tools used to build software

5.1. PHP5 programming language

PHP (recursive acronym for: PHP5: Hypertext Preprocessor) is a programming language widely used today to generate content for the WEB [17]. PHP was created in 1995 by Rasmus Lerdorf, initially being a CGI package to replace Perl Scripts. PHP initially allowed developers to create simple web applications. Currently available the "PHP 5" version released in 2004, PHP 5 was designed based on Zend Engine 2.0 and brought several innovations. The object orientation of this version of PHP has been fully rewritten to meet the new needs [18].

PHP has source code available for everyone at no cost. The license to use and edit is Open Source, meaning no one can market any modified version of PHP, and any modification must continue with Open Source code for users to explore and modify. This license system does not bring profit to developers because they make everything available to the public for free, and the public, in turn, helps by reporting bugs and helping to modify the source code. Many companies support PHP developers because they do not aim for profit by creating and developing the program. PHP is heavily used with Linux and MySQL, two other Open Source programs [18].

Other advantages of the system are: to be totally free, to work on any operating system in which it is possible to install a web server (multi-platform) and to be able to be easily connected with OpenData Base Connectivity (ODBC) standard systems [19].

Due to its great autonomy, it is a language that allows to create dynamic web sites, allowing a user interaction through forms, URL parameters and links. The difference of PHP with respect to languages similar to Javascript is that the PHP code can be executed on the server, being sent to the client only pure html. In this way, it is possible to interact with existing databases and applications on the server, with the advantage of not exposing the source code to the client. This can be useful when the program is dealing with passwords or any kind of confidential information.

5.2. The MySQL relational database system

MySQL is a relational database management system. A relational database stores data in separate tables instead of putting all the data in one place. This provides speed and flexibility [20].

SQL is the most common default language used for database access and is defined by the ANSI/ISO SQL standard. The SQL standard has been evolving since 1986, and there are several versions [21].

The MySQL is an Open Source software. Open Source means that it is possible for anyone to use and modify the program. Anyone can download MySQL over the Internet and use it without paying for it [22].

The MySQL database server is extremely fast, reliable, and easy to use. The MySQL Server also has a set of very practical features developed with the cooperation of users [21].

The MySQL Server was originally developed to handle very large databases much faster than existing solutions and has been used successfully in high demand production environments for several years [20].

The MySQL Database Program is a client/server system consisting of a multitasking SQL server that supports different accesses, various client programs and libraries, administrative tools and various programming interfaces [21].

5.3. The cascading style sheets: CSS3

Cascading Style Sheets, or Cascade Style Sheets, are formatting files for HTML documents. Its great advantage is in the association with HTML pages, which greatly facilitates the process of formatting serial pages. For example, suppose there is a site consisting of dozens of pages, and at some point it is necessary to make a change in the formatting, the background, the format of the tables, and so on. With CSS, you can associate all of these pages with a single formatting file, so that by changing the CSS file, all HTML pages associated with it are automatically cascaded, that is, when the browser reads a style sheet format the document in accordance with it [21].

The various additions to CSS 3 are extremely useful for replacing various types of images that are used to add colors and shapes to HTML elements, which you could not do with just CSS. In addition to the reduction of files to work and the absence of external dependencies that impact on the performance of the sites, the flexibility of these properties allows several combinations, which generate different styles that offer greater simplicity when creating with CSS only [23].

5.4. The HTML5 markup language

HTML is the abbreviation for Hypertext Markup Language, or Hypertext Markup Language. It is not exactly a programming language, but rather a pattern for representing elements of a web page that can be viewed in a browser program. The HTML code is sent from the server to the client computer, and the client has the task of translating this code into user-readable information [18].

The code of an HTML page consists of tags called tags, which are used to identify elements present on a page, such as text with paragraphs, line breaks, links, images, tables and so on. Each of these elements has a specific tag that identifies it. The tags are represented by the character "<", followed by the specific tag name, plus the ">"character, to start tagging [18].

Example:

```
<Html>.

<Head>.

<Title> Page title </ title>.

</ Head>.

<Body>.

This is an example page. <B > This text is bold </ b>.

</ Body>.

</ Html>.
```

With the evolution of technology, new version appeared and was called HTML5 and the emergence of HTML5 has changed many things in the world of web development, with new elements, new features and several other new features that enable better experiences and integrations that were previously only wishes and dreams of the developers. Even with some features still in the process of definition, it is already possible to take advantage of many of the new features that HTML5 has brought to the world [20].

A crucial point of these changes is that one can define several independent sections, each with its own hierarchy. For example, it is possible to have 2 h1 elements, each in its section; or you can create a header for the header of a blog, with the title and navigation links, and each post, properly created in a chapter, have a header with the title of the post and the date it was published, for example. This can be very useful for architecting more modular pages and for improving the quality and maintainability of developed code [24].

6. Software Hidrosical and Hidrosolun

6.1. Operating the Hidrosolun software

When accessing the system, the user will be redirected to the calculation screen of the solution (**Figure 1**), where you can choose the desired solution, and if you do not have any solution created, you can use the standard solution, choose the culture and the quantity of the reservoir in which the solution will be diluted, and then click next.

Solution: Default
Culture: Tomato
Tank: 1000

Figure 1. Choice of solution, culture and reservoir.

Culture chosen: Tomato
Tank Size: 1000 Liters

Select	Fertilizer
●	Calcium nitrate
○	Potassium nitrate

Figure 2. Choice of fertilizer containing nitrate.

In this step, as in the next, the system will present some fertilizers necessary to compose the solution, starting with nitrate (**Figure 2**), choose an option and click next.

The next step is to supply the solution with potassium (**Figure 3**), choose the desired fertilizer and click next. You can return the process if you have chosen the wrong fertilizer by clicking back.

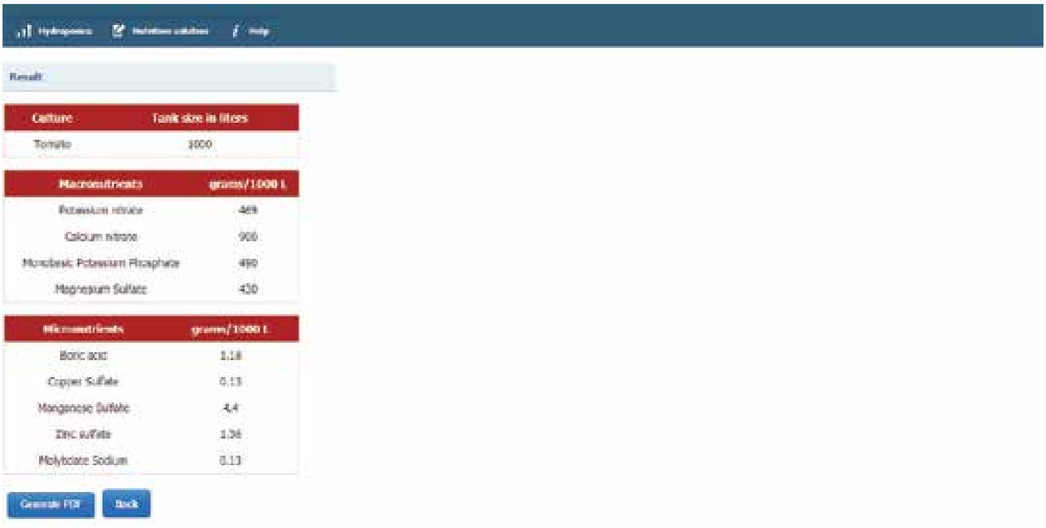
It is possible that the fertilizers used do not meet the needs of the chosen crop, being necessary the use of other fertilizers. The system calculates and lists the fertilizers that can be used (**Figure 4**) to be part of the solution, after choosing click next.

Potassium macronutrient

Culture chosen: Tomato
Tank Size: 1000 Liters

Select	Fertilizer
●	Monobasic Potassium Phosphate
○	White Potassium Chloride
○	Potassium Sulfate

Figure 3. Choice of fertilizer containing potassium.



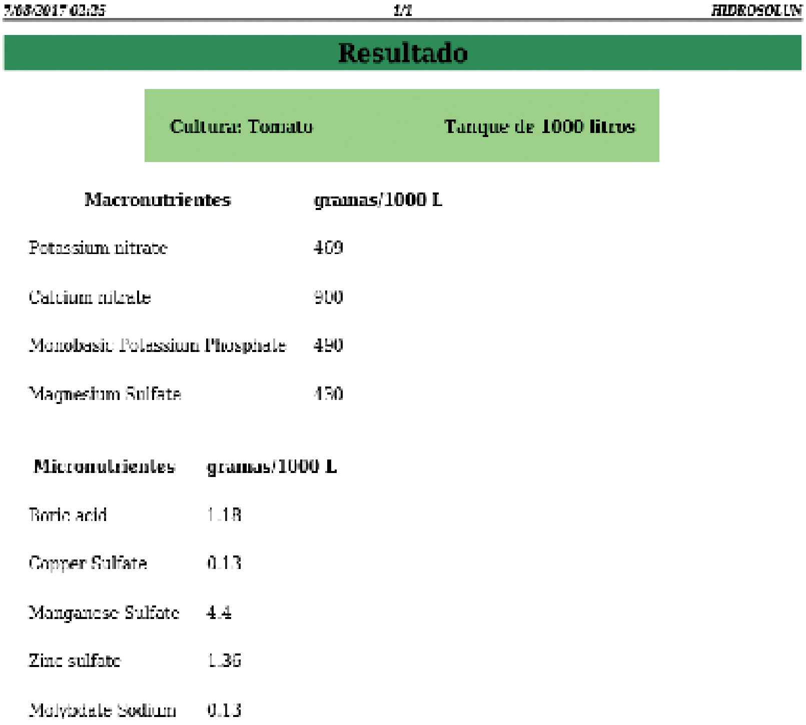
Result

Culture	Tank size in liters
Tomato	1000

Macronutrients	grams/1000 L
Potassium nitrate	469
Calcium nitrate	900
Monobasic Potassium Phosphate	490
Magnesium Sulfate	430

Micronutrients	grams/1000 L
Boric acid	1.18
Copper Sulfate	0.13
Manganese Sulfate	4.4
Zinc sulfate	1.36
Molybdate Sodium	0.13

Figure 4. Completing the calculation of the solution.



7/08/2017 02:25 1/1 HIDROSOLUN

Resultado

Cultura: Tomato Tanque de 1000 litros

Macronutrientes	gramas/1000 L
Potassium nitrate	409
Calcium nitrate	900
Monobasic Potassium Phosphate	490
Magnesium Sulfate	430

Micronutrientes	gramas/1000 L
Boric acid	1.18
Copper Sulfate	0.13
Manganese Sulfate	4.4
Zinc sulfate	1.36
Molybdate Sodium	0.13

Figure 5. Result of the calculation.

After the solution calculation process, this report (**Figure 5**) represents the result of the calculations, with the requirements of the crop, already counting the calculation of the macronutrients and micronutrients in grams.

With the possibility of generating a PDF file, just click Generate PDF. The calculations are based on nutrient solutions, which contain the amounts of nutrients that each crop needs, and knowing this, the Hidrosolun, offers an option to create nutritious solutions. On the menu bar, click Create Nutrition Solution (**Figure 6**).

Nutrition solution

Solution	Creation Date	Actions
Default	[illegible]	

Figure 6. Creating the nutrient solution.

Figure 7. Nutrient list by culture.

On this screen, all the nutrient solutions created, which can be used in the calculations, will be listed, and by clicking on the icon that appears in the table of actions, the nutrient amounts per culture can be checked (**Figure 7**).

In **Figure 8**, it is possible to enter the name of the solution, the culture and the amounts of the nutrients for the chosen crop. After this process, just click on add solution and in the table of solutions to be saved, and the solution created will be shown. If you want to create more solutions for other cultures, just repeat the process by choosing a new culture. To finish the process of creating the solution, simply click on Finish and save, and if you want to create other solutions and not save the one you created, just click on the clear button.

When you click the end and save button, the solution immediately appears in the solutions table, and you can use it in future calculations. A new option (delete—**Figure 9**) becomes available for each solution created, and after you click delete, the solution is no longer accessible to the user (**Figure 10**).

Figure 8. New nutrient solution.

Solution	Creation Date	Actions
Default	[illegible]	
Solution 1	[illegible]	

Figure 9. Delete option.

6.2. Operating the Hidrosical software

After opening the browser to the Internet, enter the address www.siscopgeo.com.br, it will appear an initial screen of presentation of the program, as well as the request of typing of the user data and the password of access. The address www.siscopgeo.com.br is a domain registered in the site "Registro.br," that is a department of the "Nucleus of Information and Coordination of Point BR" (NIC.br), a civil entity without lucrative ends, that Since December 2005 has implemented the decisions and projects of the "Internet Management Committee in Brazil," as explained in the notice to the public and in the bylaws of NIC.br. This core is responsible for registration and maintenance of domain names that use the ".br" extension.

In the pages of the system, the user can use some links that support the same and can access some entities such as Embrapa, State Secretariat of Agriculture, Ministry of Agriculture, and FAEMG, all of which contain useful information on related activities with the agricultural area. In the pages are also found access to the site "CLIMATEMPO", for queries about weather and temperature forecasts. In the footer of the pages is an application that provides the right time to visitors and also information on the number of people who have visited the site so far (**Figure 11**).

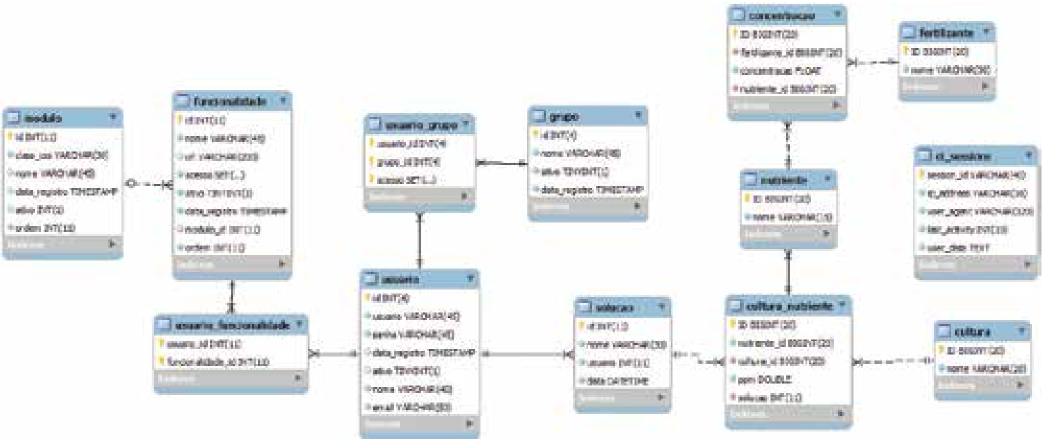


Figure 10. Diagram entity software relationship Hidrosolun.

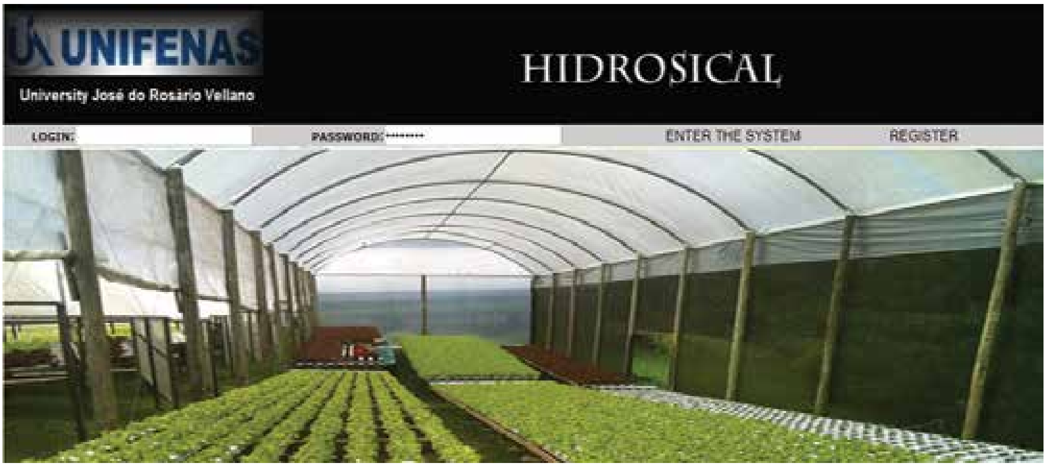


Figure 11. System login screen.

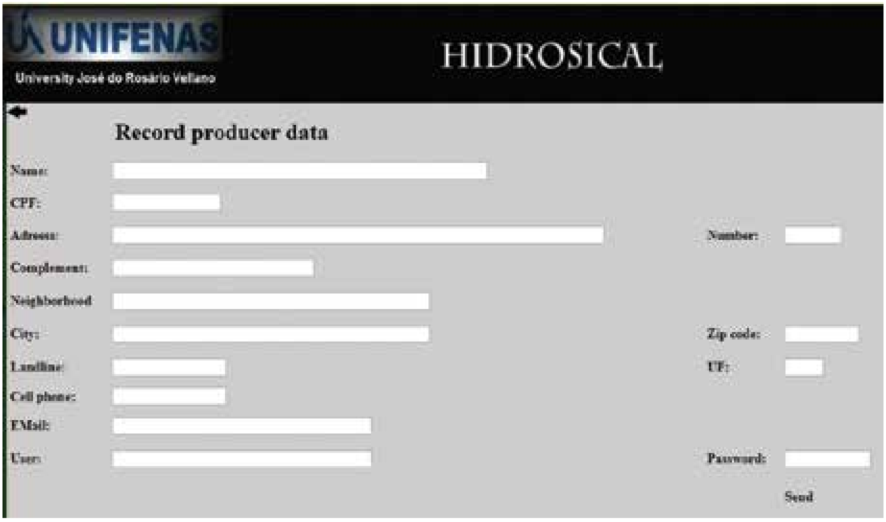


Figure 12. User registration screen.

If the user is already registered, you must enter your username and password; Otherwise, you must register by clicking the "Register" button and fill in the requested data (**Figure 12**). At the end, the "Send" button must be clicked in order for the data to be recorded. You should then return to the main screen to log in.

After typing the user name and password, click on the "Enter System" option; and you will be directed to the "Main System Menu" screen, where you can make changes to the registry, perform nutrient solution calculation, issue reports and obtain online help for system operations (**Figures 13** and **14**).

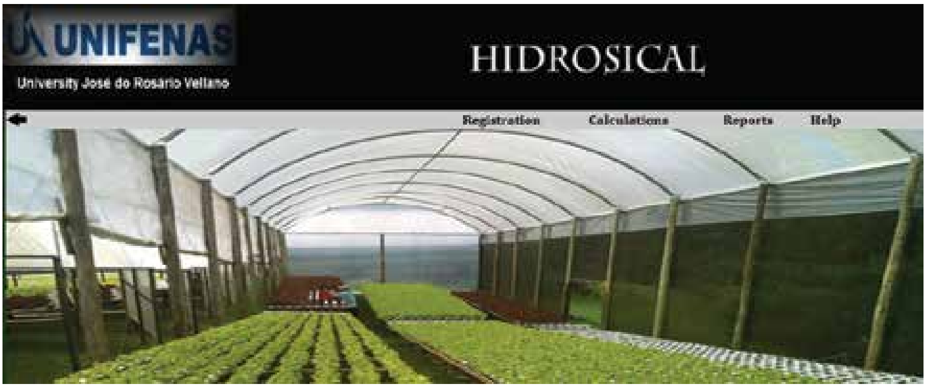


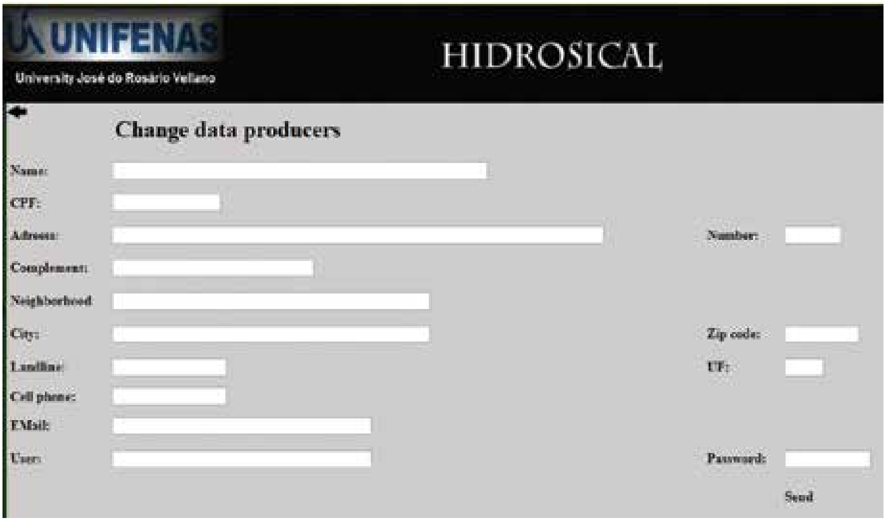
Figure 13. System main menu screen.

Figure 14. Owner or property master submenu.

To change the owner data, the user must access the "Owner" option in the menu and change the data as requested and, at the end, click on the "Send" button, this being the moment in which the data will be recorded (**Figure 15**).

To register the properties, the user must access the "Property" option in the menu and fill in the data as requested and, at the end, click on the "Send" button (**Figure 16**).

To perform the calculation of the nutrient solution, the user must choose the "Calculation" option in the menu (**Figure 17**) and fill in the data requested in the form fields. Upon accessing the nutrient solution calculation screen, the name of the user who logged in to the system will be automatically filled in the "Owner Name" field. Next, the field with the date of the calculation must be filled in, the capacity of the reservoir chosen, the lowest value being 1000 L and the maximum value 5000 L, varying 1000 L between each option. Next, the culture will be listed, in this case (e.g., lettuce). After completing all the data, the user of the system should click with the mouse on the option Send (located in the footer of the form), occasion that the system will perform the calculations and will store the data in the database.



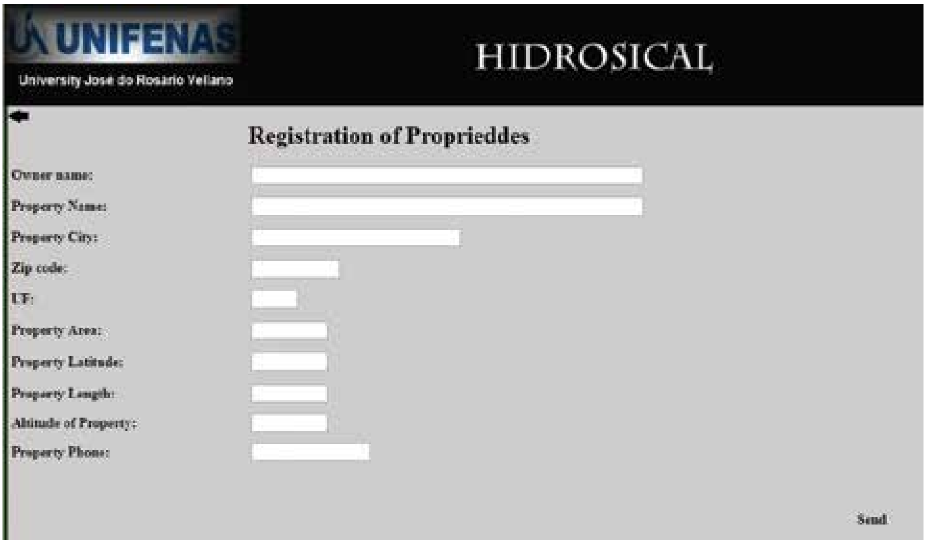
Change data producers

Name:
CPF:
Adress:
Number:
Complement:
Neighborhood
City:
Zip code:
Landline:
UF:
Cell phone:
EMail:
User:
Password:

Figure 15. Screen for changing owner data.

On the main screen of the system, the user finds the option to "report." There are several options that can be chosen: owner data report; property report; and hydroponic solution calculation report. At that point, the user has the option to view the report with the results as well as to send the report to be printed (**Figures 18** and **19**).

Issuing the report is important, because through the report the user obtains data output information from the database (**Figures 20** and **21**). Reports can be made according to the users' needs.



Registration of Proprieddes

Owner name:
Property Name:
Property City:
Zip code:
UF:
Property Area:
Property Latitude:
Property Length:
Altitude of Property:
Property Phone:

Figure 16. Properties master screen.

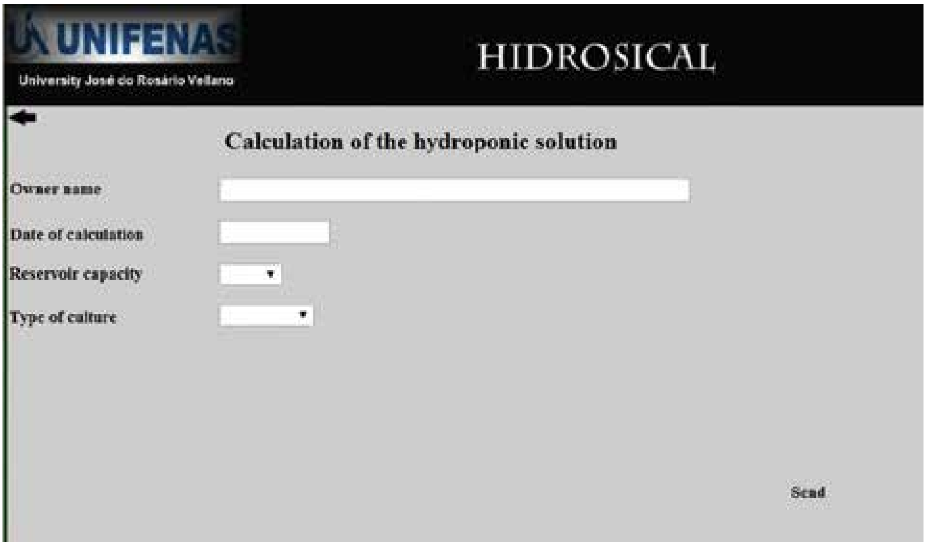


Figure 17. Screen for calculating the solution.

By choosing the menu option reports, a new window will open, allowing you to choose by report type, which may be the owner, property or result of the calculation of the solution.

By choosing the "Owner" option, the owner data report will be displayed on the screen, presenting the option to send to the printer.

By choosing the "Property" option, the property report will be displayed on the screen, with the option to be sent to the printer (**Figure 16**).

Figure 18. Menu screen for reporting.

Figure 19. Menu for choosing the report type.

Owner report

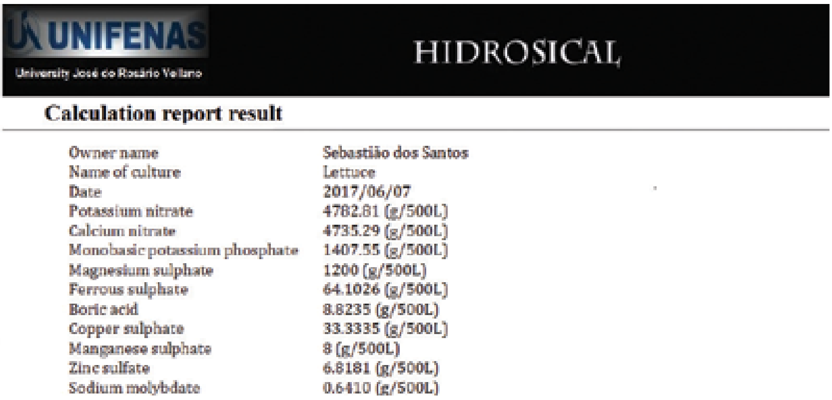
Name:	Jose Santos
CPF:	453.675.782-45
Street:	Getulio Vargas
Number:	376
Neighborhood:	Center
City:	Alfenas
Zip Code:	37130-000
State:	MG
Telefone Fixo:	45346756
Celular:	956234967
Email:	José@hotmail.com

Figure 20. Owner report template.

Property report

Name	Good retreat site
City	Alfenas
Zip Code	37130-000
UF	MG
Area	3,5 ha
Latitude	23:45:32
Longitude	45:23:43
Altitude	870 m
Landline	3292-5645

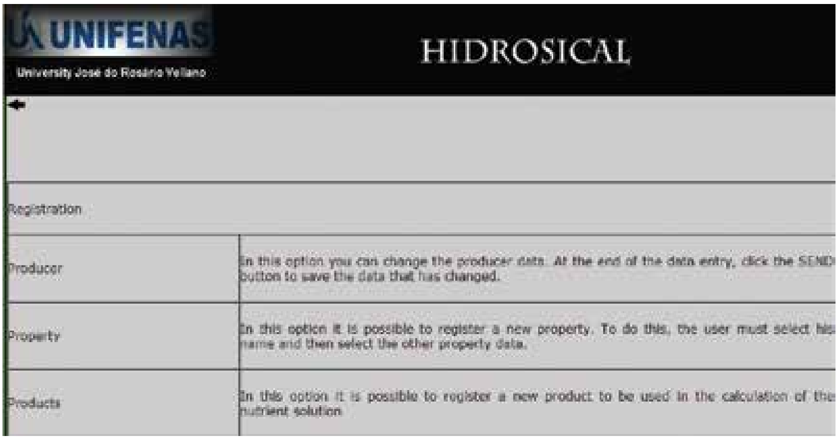
Figure 21. Property report template.



Calculation report result

Owner name	Sebastião dos Santos
Name of culture	Lettuce
Date	2017/06/07
Potassium nitrate	4782.81 (g/500L)
Calcium nitrate	4735.29 (g/500L)
Monobasic potassium phosphate	1407.55 (g/500L)
Magnesium sulphate	1200 (g/500L)
Ferrous sulphate	64.1026 (g/500L)
Boric acid	8.8235 (g/500L)
Copper sulphate	33.3335 (g/500L)
Manganese sulphate	8 (g/500L)
Zinc sulfate	6.8181 (g/500L)
Sodium molybdate	0.6410 (g/500L)

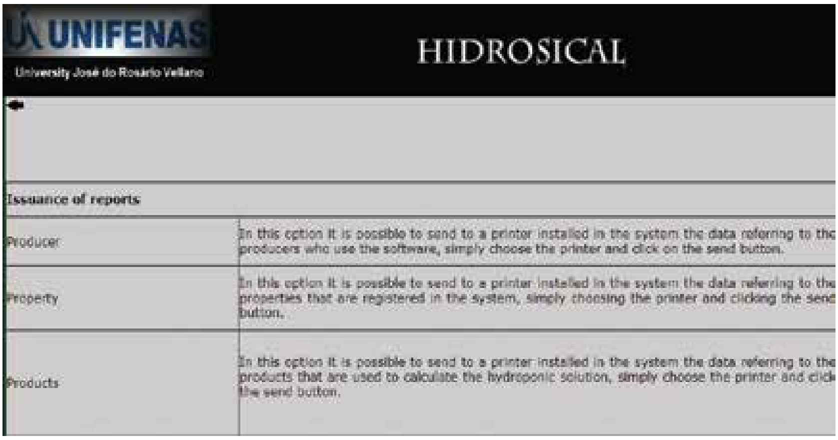
Figure 22. Result calculation model of the solution calculation.



Registration

Producer	In this option you can change the producer data. At the end of the data entry, click the SEND button to save the data that has changed.
Property	In this option it is possible to register a new property. To do this, the user must select his name and then select the other property data.
Products	In this option it is possible to register a new product to be used in the calculation of the nutrient solution

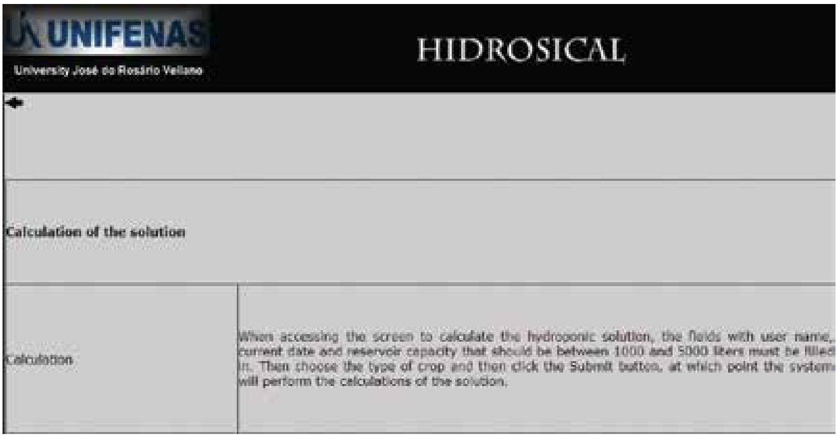
Figure 23. Help menu screen for log files.



Issuance of reports

Producer	In this option it is possible to send to a printer installed in the system the data referring to the producers who use the software, simply choose the printer and click on the send button.
Property	In this option it is possible to send to a printer installed in the system the data referring to the properties that are registered in the system, simply choosing the printer and clicking the send button.
Products	In this option it is possible to send to a printer installed in the system the data referring to the products that are used to calculate the hydroponic solution, simply choose the printer and click the send button.

Figure 24. Reporting menu help screen.



Calculation of the solution

Calculation	When accessing the screen to calculate the hydroponic solution, the fields with user name, current date and reservoir capacity that should be between 1000 and 5000 liters must be filled in. Then choose the type of crop and then click the Submit button, at which point the system will perform the calculations of the solution.

Figure 25. Hydroponic solution calculation help menu screen.

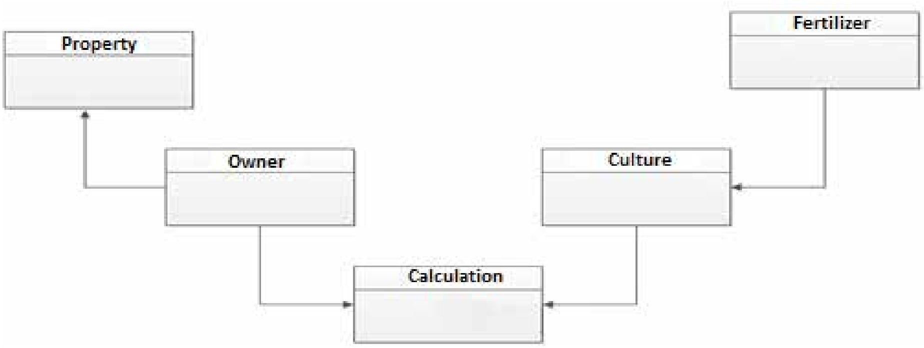


Figure 26. Diagram entity relationship of Hidrosical software.

In the "Calculation" option, the report on the calculation data of the solution will be shown on screen and can be sent to the printer (**Figure 22**).

In the main menu screen of the System, the user has the "On-line Help" available, where the procedures for the operation of the system are described, in their entirety, from registration, calculation and reporting (**Figures 23–26**).

7. Final considerations

The software for calculation of nutrient solution for fruit and leaf vegetables in hydroponic system-NFT is easy to use, has simple interface with little input data and does not need installation, since it is an application available on the Internet.

The system calculates the amount of fertilizers needed to meet the needs of each crop available in the software, and it is possible to size the reservoir of the nutrient solution. It is a tool of extreme importance, especially for professionals in the area of Agrarian Sciences, who provide advice in the area of Mineral Fertilization and Plants.

The developed system calculates the amount of fertilizers used in the preparation of the nutrient solution, used in the hydroponic system, for hardwood vegetables, facilitating the calculation of the solution. The software is available for access on the WEB, without the need to download the program, and can still be used on mobile devices, such as cell phones or smartphones.

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The book *Potassium - Improvement of Quality in Fruits and Vegetables Through Hydroponic Nutrient Management* provides useful information regarding potassium nutrition management in hydroponic cultivation, which will help in producing quality horticultural crops. The first few chapters describe the role of potassium nutrition in plants, its interaction with other nutrients, its source fertilizers, the role in postharvest produce qualities, and human nutrition. Potassium fertilizer management, its metabolism in plants, and cultivation techniques of fruits and leafy vegetables are also included in the middle section. The final chapter illustrates the software development for the calculation of hydroponic nutrients including potassium for easy management of cultural solution. As a whole, this book covers several major aspects on the topic for making it a complete and useful resource.

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