Review Article

NUTRIENT DYNAMICS FOR HYDROPONIC PRODUCTION SYSTEM

ABSTRACT

As our world has become more populated and cities have grown, the amount of land available for farming per person has gone down a lot. Back in 1960, when there were 3 billion people, each person had about half a hectare of land for farming. But now, with 6 billion people, it's down to just a quarter of a hectare, and it's expected to shrink even more to just a tiny 0.16 hectares by 2050.Several things are making this problem worse. Cities and industries are expanding, and climate change is causing icebergs to melt, which can flood and ruin farmland. Also, the soil that we grow crops in has reached a point where it can't get much more fertile, even if we use more and more fertilizers. Some areas have really poor soil, and the natural process of soil getting better with time is getting disrupted because we keep farming the same land over and over. On top of that, there are more droughts, unpredictable weather, higher temperatures, pollution in rivers, and wasteful water use. All these challenges are making it harder to grow enough food using traditional farming with soil. That's why soil-less farming, where plants grow without soil, is becoming more important. It's a way to produce food that uses less space and water, and it's showing some good results around the world.

KEYWORDS: Hydroponics, Nutrient solution, Ph, EC, solution temperature, plant nutrients, soil-less culture.

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INTRODUCTION

By 2050, nearly 70% of the world's population will be living in cities, up from 55% today. To make enough food for everyone, we'll need to turn a huge amount of new land into farms, about 593 million hectares. But there's a problem. when we use the land too much, it causes other issues. The soil loses its nutrients, and farms don't produce as much food. We also use up too much water from underground, and pests like weeds and bugs become big problems (Debangshi, 2021). To address these challenges, we propose the implementation of a hydroponic system. This innovative approach offers a solution to the above issues by allowing for the cultivation of plants in a controlled, soil-less environment. Hydroponics is a way to grow plants using special nutrient-rich water, sometimes with things like gravel or coconut fibre to support them, but sometimes just the water alone (Sharma *et al.,* 2018). Hydroponics involves growing plants without soil, where their roots are submerged in a nutrient solution (Maharana and Koul, 2011). Hydroponics is a great way to grow plants without soil, and it's good for making money, taking care of the environment, and being sustainable. Growers frequently assert that hydroponically grown produce exhibits superior quality due to its utilization of a tightly controlled environment, allowing for more consistent production without water and nutrient loss. Furthermore, hydroponics is not subject to seasonal limitations, resulting in consistently higher and uniform yields year-round (Okemwa, 2015). Effective nutrient solution management is a critical factor for achieving success in hydroponics. The quality of the food you produce and how effectively your plants develop depend largely on it. Plants receive all the nutrients they require in the ideal balance from the nutrition solution. You must match the fertilizer mix to what your plants actually use for it to perform effectively. The proper balance of nutrients is crucial for hydroponic systems to function well and yield the best crops. To achieve the highest potential crop output, you also need to monitor and manage the pH, electrical conductivity, oxygen levels, and temperature of the fertilizer solution (Meselmani, 2023).

EFFECTIVE PLANT NUTRIENTS

In hydroponic systems, the primary method of delivering plant nutrients is through nutrient solutions. The nutrient solution in hydroponic systems is a watery combination that mostly contains inorganic ions from soluble salts, giving plants the critical components, they require to flourish. Sometimes the solution may also contain some organic substances, such as iron chelates. Creating a special mix of chemicals to give plants everything they need to grow is crucial when you're growing crops without soil. This mix of nutrients should have the right balance of ions to help plants grow well. It's a really important step in hydroponic farming (Van *et al.,*2021). Plants primarily absorb nutrients when they are in usable form. Generally, plants

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take in nutrients in a charged state, these charged states can either be positive, known as cations, or negative, referred to as anions. Plants can get nitrogen in two main ways: as ammonium (NH_4^+), which is like a positively charged nutrient, or as nitrate (NO_3^-), which is like a negatively charged nutrient. These are the two forms of nitrogen that plants use to grow.Plant growth is a complex process that needs a variety of essential components to proceed in the best way possible. Mineral elements and non-mineral elements are the two groups into which these substances can be categorized. These constituents can be broadly classified into two major groups: mineral elements and non-mineral elements.

Mineral Nutrients: These are essential nutrients that plants need in relatively large quantities. They include elements like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). These minerals are typically provided in the form of water-soluble salts in the hydroponic nutrient solution. They play vital roles in plant growth, such as forming the structure of plant cells and aiding in various metabolic processes.

Non-Mineral Nutrients: These are nutrients that plants need in smaller quantities but are still essential for their growth. They include elements like iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl). These micronutrients are also provided in the hydroponic nutrient solution, albeit in smaller amounts. They are crucial for various enzymatic reactions and other biochemical processes within the plant.

Table 1. The nutrients

Macronutrients:
Nitrogen (N)
Nitrogen plays a pivotal role in hydroponic production systems as it is an essential component of plant proteins, enzymes, and chlorophyll. It supports vigorous vegetative growth, helps plants maintain their vibrant green color, and contributes to overall plant health and productivity in hydroponic environments.
Phosphorus (P)
Phosphorus is crucial in hydroponic production systems as it aids in energy transfer and storage within plants. It plays a vital role in root development, flowering, and fruiting,

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ensuring healthy and robust growth, ultimately leading to higher yields in hydroponic setups.

Potassium (K)

Potassium is essential in hydroponic production systems as it regulates various physiological processes in plants. It helps in water uptake, enhances drought tolerance, and contributes to the overall quality and taste of the harvested produce in hydroponic cultivation.

Calcium (Ca)

Calcium is essential in hydroponic production systems because it provides structural support to cell walls, preventing diseases such as blossom end rot in fruiting plants. It promotes appropriate growth by assisting with nutrient uptake and transport, and it contributes to the general strength and resilience of plants in hydroponic conditions.

Magnesium (Mg)

Magnesium is essential in hydroponic production systems since it is a component of chlorophyll, the pigment that performs photosynthesis. It promotes healthy leaf development and efficient energy production in hydroponic plants by boosting glucose synthesis and influencing enzyme activity.

Sulfur (S)

Sulfur is important in hydroponic production systems because it aids in the creation of critical amino acids and vitamins within plants. It promotes chlorophyll synthesis, which contributes to the green color of leaves, and it supports plants in surviving stress and illness in hydroponic conditions.

Micronutrients:

Chlorine (Cl)

Chlorine is essential in hydroponic production systems because it helps maintain osmotic pressure within plant cells. It contributes to the maintenance of cell turgor pressure, which is necessary for optimal water and nutrient transfer and the healthy growth and development of hydroponically cultivated plants.

Iron (Fe)

Iron is necessary in hydroponic production systems because it is a necessary component for chlorophyll formation, which allows plants to perform photosynthesis efficiently. Adequate iron levels in the fertilizer solution prevent plant leaf yellowing (chlorosis) and promote healthy development and photosynthesis, resulting in higher yields in hydroponic setups.
Boron (B)
Boron is necessary in hydroponic production systems because it promotes cell wall development and influences pollen generation, both of which are required for plant reproduction. In hydroponic systems, adequate boron levels in the fertilizer solution increase overall plant health and reproductive performance.
Manganese (Mn)
Manganese is essential in hydroponic production systems because it is involved in enzyme activation, notably in photosynthesis-related enzymes. In hydroponic cultivation, it enables adequate energy production, chlorophyll creation, and general plant health.
Zinc (Zn)
Zinc is a critical element for enzyme function in hydroponic production systems, particularly those involved in photosynthesis and hormone regulation. In hydroponic conditions, it promotes overall plant health, growth, and development.
Copper (Cu)
Copper is crucial in hydroponic production systems because it participates in a variety of enzymatic activities that contribute in the creation of key chemicals. In hydroponic cultivation, it promotes plant metabolism, disease resistance, and overall health.
Molybdenum (Mo)
Molybdenum is necessary in hydroponic production systems because it functions as a cofactor for enzymes involved in nitrogen assimilation. It allows plants to use nitrogen from the nutrient solution more efficiently, promoting protein synthesis and total plant development in hydroponic systems.
Nickel (Ni)
As a micronutrient involved in the activation of specific enzymes, nickel plays an important

role in hydroponic production systems. It contributes to nitrogen metabolism and general plant health and growth in hydroponic conditions.

Table 2. **Available forms of various nutrients**

Nutrients	**Available form (mg/L)**
Nitrogen	NH_4^+, NO_3^-
Potassium	K^+
Magnesium	Mg^{2+}
Phosphorus	HPO_4^{-2}, $H_2PO_4^-$
Calcium	Ca^{2+}
Boron	H_3BO_3, BO_3^-, $B_4O_7^{2-}$
Copper	Cu^{2+}
sulfur	SO_4^{2-}
Iron	Fe^{2+}, Fe^{3+}
Molybdenum	MoO_4^{2-}
Zinc	Zn^{2+}
Manganese	Mn^{2+}, Mn^{4+}

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NUTRIENT SOLUTION CONCENTRATION

Steiner in 1961 described the nutrient solution for hydroponic systems as an aqueous solution primarily comprised of inorganic ions derived from soluble salts containing essential elements required for plant growth. Additionally, there may be some presence of organic compounds such as iron chelates. In 1938, Dennis R. Hogland and Daniel I. Arnon, researchers at the University of California, pioneered water culture methods for cultivating plants without soil, as noted by. In the most basic nutrient solutions, which focus on nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, micronutrients are typically added as supplements. McEvoy (2000) demonstrated that for non-organic hydroponic production, the majority of plant nutrients are provided in readily available forms, with the key factor being the management of fertilizers.

(Vernieri *et al.*, 2006) employed a bio-stimulant called Actiwave at a concentration of 0.3 ml/L in combination with a 10% nutrient solution in their study and found that the yield was higher when using lower concentrations of Actiwave.

(Burnett *et al.*, 2008) reported that plants fertilized with either the highest (80 mg/L) or lowest (0 mg/L) concentrations had notably shorter stems and smaller shoot dry weights and leaf areas compared to plants fertilized with concentrations ranging from 20 to 60 mg/L of phosphorus. In the case of P. Fan flowers, those fertilized with 0, 60, and 80 mg/L had fewer flowering branches and flowers compared to those fertilized with 20 to 40 mg/L of phosphorus. (Nada *et al.*, 2010) suggested that the critical concentration of Boron in the nutrient solution for long-term hydroponic tomato cultivation is 4 ppm.

(Nurzynska*et al.*, 2012) found that plants fed with medium and high doses of nitrogen exhibited significantly higher fresh and air-dry herb weights. Bever (2013) observed that Beta Vulgaris plants treated with readily available nitrogen showed higher photosynthetic rates, evapotranspiration, intercellular CO_2 concentration, and chlorophyll content.

(Mabako and Du Plooy,2017) reported that plants fertigated with a 25% nutrient solution concentration tended to yield less in the market. Increasing the nutrient solution concentration to 75% significantly increased the total number of fruits and overall yield compared to the 25% concentration. Among all the treatments, the highest total yield, plant fresh and dry weight, and marketable yields were not significantly different at 50%, 75%, and 100% nutrient solution concentrations, respectively. The greatest total and marketable yields were achieved with plants grown at 75% and 100% nutrient solution concentrations compared to 50% and 25% concentrations.

Table 3. Nutrient solutions for various types of plants

Crop	N	P	K	Ca	Mg

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Concentration in mg/L(ppm)					
Tomato	190	40	310	150	45
Pepper	190	45	285	130	40
Melon	200	45	285	115	30
Roses	170	45	285	120	40
Strawberry	50	25	150	65	20
Cucumber	200	40	280	140	40

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COMPOSITION OF THE NUTRIENT SOLUTION

Nutrient solutions typically comprise six essential elements: nitrogen (N), phosphorus (P), sulfur (S), potassium (K), calcium (Ca), and magnesium (Mg). Steiner introduced the concept of ionic mutual ratio, which is based on maintaining a proportional balance between anions (e.g., NO_3^-, $H_2PO_4^-$, and SO_4^{2-}) and cations (e.g., K^+, Ca^{2+}, and Mg^{2+}). This relationship goes beyond simply considering the total quantity of each ion in the solution; it underscores the precise quantitative equilibrium among these ions. If this equilibrium is disturbed, it can have a detrimental effect on plant performance(Steiner1961 and 1968).

The ionic balance constraint renders it infeasible to introduce a single ion without concurrently introducing a counter ion. Any alteration in the concentration of one ion necessitates a corresponding adjustment in an ion of opposite charge, a complementary modification in ions of similar charge, or a combination of both (Hewitt, 1966).

Table 4. Concentration ranges of essential mineral elements according to various authors (adapted from Cooper, 1988; Steiner, 1984; Windsor & Schwarz, 1990).

Nutrient	Hoagland & Arnon (1938)	Hewitt (1966)	Cooper (1979)	Steiner (1984)
	mg/L			
N	210	168	200-236	168
P	31	41	60	31
K	234	156	300	273
Mg	34	36	50	48
Ca	160	160	170-185	180
Fe	2.5	2.8	12	2-4
S	64	48	68	336
Zn	0.05	0.065	0.1	0.11
B	0.5	0.54	0.3	0.44
Cu	0.02	0.064	0.1	0.02
Mn	0.5	0.54	2.0	0.62
Mo	0.01	0.04	0.2	Not considered

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OSMOTIC POTENTIAL OF NUTRIENT SOLUTION

Water consumption exhibited an increase throughout the freshwater crop cycle, while in the case of brackish water, consumption decreased by up to 33.10%. This phenomenon can be attributed to osmotic potential. (Guimaraes*et al.,* 2017) found that lettuce production during its growth cycle significantly decreased as electrical conductivity and, consequently, osmotic pressure increased. The stress induced by exposure to saline conditions interferes with essential plant functions such as photosynthesis and protein synthesis. Saline stress hampers plant growth primarily through its osmotic effect, which limits water availability and leads to nutritional imbalances. In hydroponic lettuce production, the Nutrient Film Technique system yielded satisfactory results with a nutritive solution electrical conductivity of up to 3.5 ds m-1.

pH IN HYDROPONICS

In hydroponics, pH is like a measuring stick that tells us if a liquid is more on the acidic or alkaline side. It's a number that shows how many H+ (hydrogen) and OH- (hydroxide) ions are in the liquid. The scale goes from 0 to 14. When it's closer to 0, the liquid is very acidic, and when it's closer to 14, it's very alkaline. If it's right in the middle at 7, it's considered neutral, like pure water. According to Mayavan and his team, maintaining a specific pH range is critical to ensuring that plants can use all of the nutrients they require (Mayavan *et al*., 2017). The pH of the nutrient solution is normally kept between 5.5 and 6.5 in hydroponics. This range appears to work well for the majority of hydroponically grown crops, allowing them to grow regularly and absorb the nutrients they require. When cultivated hydroponically, different crops may have different optimum pH values. Leafy greens grown in liquid culture hydroponic systems exhibit species-specific pH reactions that have largely gone unstudied (Gillespie *et al*., 2021). Also, the best pH for making them grow the most isn't the same for all types of greens. It can vary depending on the specific type of plant, the variety, the weather, and even the type of soil, substrate, or nutrient solution being used (Islam *et al.*,1980). When the pH level deviates significantly from the ideal range, whether it is excessively high or exceedingly low, it can disrupt the nutrient balance within plants and consequently result in reduced growth rates (Gillespie *et al.*, 2020).

However, these issues typically become critical when the pH reaches extreme levels, either highly acidic or highly alkaline. In cases where the pH only slightly falls outside the normal range, any growth or nutrient-related problems are often connected to factors influenced by the specific pH level. The pH of the soil around plant roots can affect how well nutrients are absorbed by plants, the availability of nutrients, the types of ions present, and the rate at which fertilizer salts dissolve. Because of this, it's critical to measure and keep the pH level at the desired level because even a small pH value drift can prevent plants from accessing a lot of nutrients (Mayavan*et al*., 2017). The pH of the soil around plant roots can affect how well nutrients are absorbed by plants, the availability of nutrients, the types of ions present, and the rate at which fertilizer salts dissolve.

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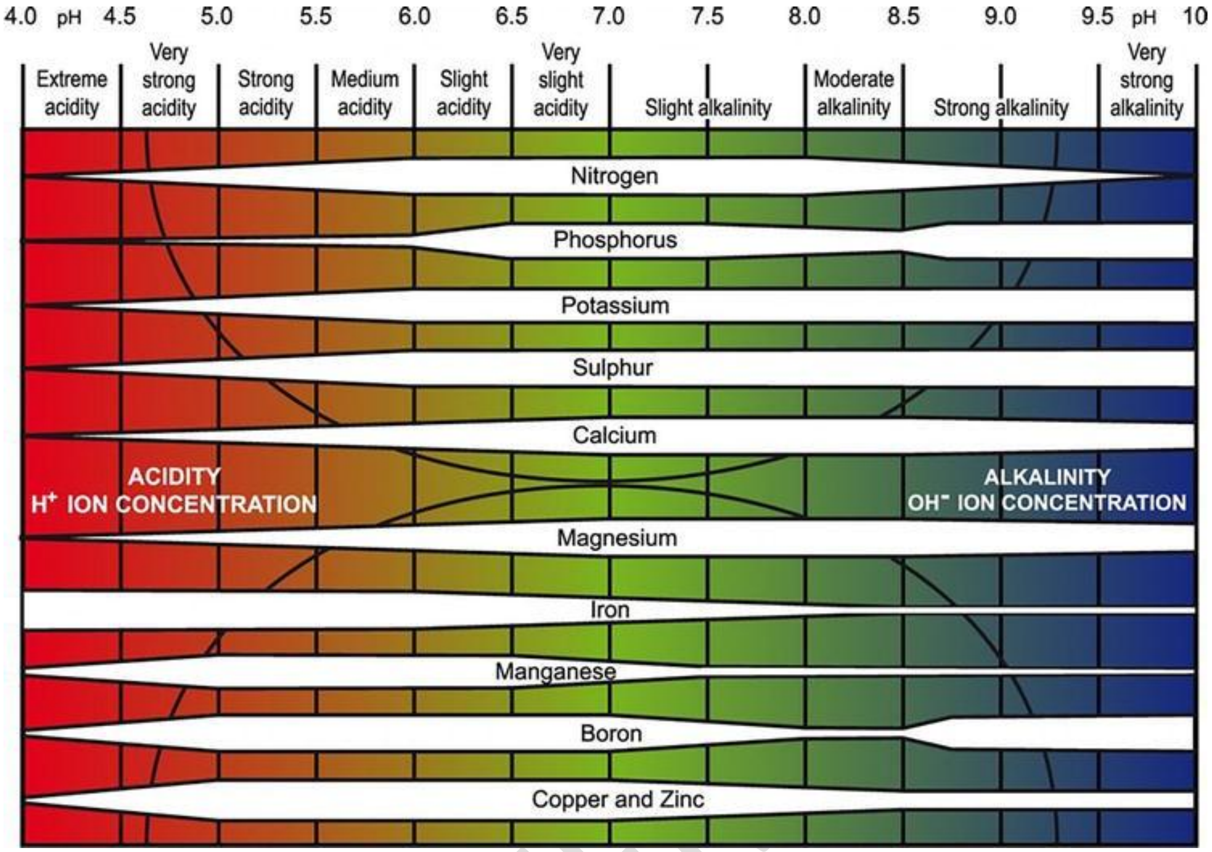

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Figure 1. The availability of different nutrients at the different pH bands is indicated by the width of the white bar: The wider the bar, the more available is the nutrient. Source: (Truog, 1947)

ELECTRICAL CONDUCTIVITY IN NUTRIENT SOLUTIONS

In soilless farming, we need to pay attention to how much salt is in the nutrient solution we give to plants. Electrical conductivity (EC) is like a signal that tells us how much salt is in the water. It's like a way to count how many tiny particles (ions) are in the water that plants use for their roots. So, when we measure EC, we're checking how salty the water is. It helps us know if we're giving the right amount of nutrients to the plants. However, it doesn't tell us exactly which nutrients are in there. It's a general way of saying how much stuff, both big and small, the plants can use. In simple words, EC is like a saltiness gauge for plant food, and it's a handy and accurate tool to see how much stuff is in the water that plants need to grow (Van*et al*., 2021).If you don't get the plant food mixture just right by using too much or too little, or if it doesn't havethe right mix of nutrients, it can stop the plants from growing well. This is feasible because the plants either get too much of some nutrients, which is like a poison for them, or they don't get enough of what they need to grow, like missing out on important nutrients. So, making sure the plant food mixture is just right really important for healthy plant growth (Grattan and Grieve, 1998).But, keeping the electrical level in the water a bit high (not too high) can be a useful way to grow really tasty and nutritious vegetables. You can do this by using water with some leftover minerals in it, like chlorine, sodium, and sulphate, or by adding important nutrients to the water. This technique can help make sure your fresh veggies are both healthy to eat and taste great.

Numerous research findings have highlighted the influence of nutrient solution electrical conductivity (EC) on the growth of different crop varieties. While the ideal EC range generally falls between 1.5 to 3.5 dS m−1 for most hydroponic crops, it's important to note that this range may vary depending on the specific crop species and their growth stages (Van *et al.*, 2021). Both excessively low and excessively high EC levels can result in reduced yields, compromised visual quality, diminished phytochemical compounds, and an unappealing appearance and taste for consumers. Additionally, they can exacerbate health concerns related to the accumulation of nitrates (Yang *et al.*, 2021). Elevating the conductivity in the nutrient solution can lead to a decrease in water uptake by plants and a reduction in the rate of photosynthesis (Suhardiyanto *et al.*, 2020).Moreover, an elevated EC exposes plants to salinity stress and elevated nutrient levels, impeding nutrient absorption and causing osmotic stress, ion toxicity, and nutrient imbalances. This not only leads to nutrient wastage but also results in the increased release of nutrients into the environment, contributing to environmental pollution. At excessively high EC levels, plants reach a point where they can no longer absorb additional water, causing them to wilt. Although heightened EC levels can have negative implications for yield, they can also enhance the quality of fresh produce, offsetting yield losses through the production of high-value products (Chrysargyris *et al.*, 2021). Reduced EC values often signify insufficient nutrient supply to the crop, leading to nutrient deficiencies and a decline in yield (Samarakoon*et al.*, 2006). Therefore, effective EC management in hydroponic techniques can serve as a valuable tool for enhancing both the yield and quality of vegetables(Sharma *et al.*, 2018).

TEMPERATURE OF THE NUTRIENT SOLUTION FOR PLANT GROWTH

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The environmental temperature impacts plant development by changing the speed of seed germination, root expansion, the pace of photosynthesis, transpiration, and respiration (Khan *et al.*, 2020). Most greenhouse-grown crops tend to thrive at ideal temperatures ranging from approximately 21 to 27 C (Kawasaki and Yoneda, 2019). Within indoor environments, both the temperature of the light and the surrounding air play pivotal roles in shaping plant growth. This impact extends to alterations in the growth of leaves and stems, the initiation of fruit formation, the progression of fruit growth, the ripening of fruit, and the overall quality of the produce. Notably, a significant fluctuation between day and night temperatures resulted in taller plant growth with shorter leaves (Khan *et al.*, 2020). Nutrients are delivered to the roots in hydroponics by a nutrient solution that circulates throughout the system. The temperature of the nutrient solution can be adjusted to determine how much oxygen plants use (Trejo and Gómez, 2012). The temperature of the fertilizer solution controls the optimal growth temperature of each plant. Villela, Luiz, Araujo, and Factor (2004) examined better strawberry production by cooling the nutrient solution to 12 C. Several research have been undertaken to investigate how the temperature of the fertilizer solution affects fruit quality (Trejo and Gómez, 2012). Monitoring the rootzone temperature is essential. Lower temperatures lead to reduced root length, affecting overall root growth and density. Conversely, elevated temperatures can impair root functionality (Koevoets *et al.*, 2016).

In order to evaluate the impact of temperature on oxygen solubility, **Table5,** provides data for temperatures commonly encountered within greenhouses. It illustrates the direct relationship between temperature and the amount of oxygen consumed by plants, as well as the inverse relationship with the dissolved oxygen levels in the nutrient solution.

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Table 5. The oxygen's ability to dissolve in pure water at different temperatures under 760 mm Hg of atmospheric pressure.

Temperature, ℃	**Solubility of oxygen in pure water, in (mg/L).**
10	11.29
15	10.08
20	9.09
25	8.26
30	7.56
35	6.95
40	6.41
45	5.93

OXYGEN CONCENTRATION WITHIN THE NUTRIENT SOLUTION

A lack of oxygen in plants might have negative consequences. Plants' oxygen consumption is affected by the temperature of the nutrient solution as well as their photosynthetic activity (Papadopoulos *et al.,* 1997). When plant roots lack proper aeration, the concentration of CO_2 increases (Morard and Silvestre, 1996). It has been observed that dissolved oxygen levels below 3-4 mg/L have adverse effects on plant roots, resulting in browning and diminished root growth (Gislerød and Adams, 1983). Pedersen and colleagues documented that when faced with challenging conditions, plants can alter their root structure and anatomy to ensure the ongoing functionality of their roots in low-oxygen soil (Pedersen *et al.*, 2021). Plants cultivated in hydroponic systems could encounter oxygen insufficiencies. A reduction in oxygen levels was noted when employing the NFT (Nutrient Film Technique) (Suhl *et al.*, 2019). Furthermore, as roots become intertwined, the flow velocity of the nutrient solution decreases, signifying a reduced rate of oxygen transport to the densely packed root layers (Blok *et al.*, 2017). To ensure water and nitrate uptake processes in situations of root hypoxia, plants may utilize the oxygen from the reduction reactions of nitrates to nitrites (Morard*et al.*, 2000). In situations where aerobic respiration shifts to glycolytic ATP synthesis, there is a significant reduction in the amount of energy available for uptake, growth, and maintenance. This shift comes at the expense

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of decreased growth and productivity (Koevoests *et al.*, 2016), (Shaw *et al.*, 2013). Aeration promotes plant development, leaf K, P, Mg, water intake, and the net photosynthetic rate of the plant (Pezeshki and Santos, 1998). Oxidation is a common procedure in soilless commercial agriculture, and numerous oxygenation systems are used (Oztekin and Tuzal, 2020).

PROVISION OF NUTRIENTS TO THE PLANTS

In hydroponics due to the system's insufficient ability to buffer nutrients and its capacity to facilitate swift adjustments, it is essential to maintain the system with care. Two key aspects of nutrition necessitate attention: the provision of nutrients via the nutrient delivery system and the plant's response to nutrient availability. Critical nutrient levels have been established for the majority of common crop plants, and sources of nutrient elements, along with their specific characteristics, are provided for reference.

SOURCES OF NUTRIENT ELEMENTS:

Table 6. Provision of nutrients to the plants with their characteristics.

Source	**Element**	**Characteristics**
Potassium nitrate KNO_3	N, K	Very soluble salt
Magnesium sulfate $MgSO_4$	S, Mg	Cheap, highly soluble, pure salt
Calcium nitrate $Ca(NO_3)_2$	N, Ca	Very soluble salt
Potassium phosphate	P, K	Corrects

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monobasic KH_2PO_4		phosphorus deficiency
Iron chelates	Fe Cit	Best sources of iron
Boric acid H_3BO_3	B	Best source of boron

The frequency and quantity of nutrient solution application vary based on several factors, including the substrate type (both its volume and physical-chemical properties), the specific crop being grown (its species and growth stage), container dimensions, the installed irrigation system, together with the current weather. It is essential to provide daily nutrient feedings to the plants while considering these factors. The optimal timing for dispensing the nutrient solution is typically between 6:00 and 8:00 a.m., although it's important to note that the water needs of plants can fluctuate significantly throughout the day and from one day to the next. When applying the solution, it's advisable to target the plant's root zone, taking care to prevent moisture from coming into contact with the leaves. This precaution helps minimize the risk of damage and the onset of diseases. It is crucial to ensure that plants never experience water stress under any circumstances, as this can negatively impact their final yield (De Kreij*etal.*,2003). It is commonly advised to irrigate the plants with just plain water once a week. This practice helps to flush out any accumulated excess salts. Utilize twice the usual amount of water for irrigation, but refrain from adding any additional nutrients during this process. The surplus nutrient solution that drains from the containers during daily watering can be recycled for subsequent watering. However, at the week's conclusion, it is advisable to dispose of this liquid.

NUTRIENT SOLUTION FLOW RATE IN HYDROPONIC SYSTEMS

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The growing scarcity of water resources and the deterioration of arable land present formidable hurdles for conventional agriculture in dryland regions (Solh and Van Ginkel, 2014). In recent times, advancements in light-emitting diode (LED) technology have made it possible to practice cost-effective indoor cultivation by employing artificial lighting (Yeh and Chung, 2009) and soilless techniques (Maneejantra*et al., 2016*). This innovation facilitates plant production in locations where traditional crop growth is unfeasible. Hydroponics is a special way of growing plants that saves a lot of water (Sheikh, 2006). It's often used in areas with not much rain. Instead of regular soil or other materials, hydroponics uses a special liquid with all the plant nutrients. It also uses fancy technology to control things like how acidic the liquid is, how conducive it is, and the temperature (Jones, 2016). Because of the liquid, nutrients move around differently in hydroponics compared to regular soil. In regular soil, plant nutrients reach the roots. in three ways: first, the nutrients go with the flowing water, the roots spread out toward them, and third, they slowly spread through the soil to reach the roots (Barber *et al*., 1963). But in hydroponics, where plants grow in a liquid filled with nutrients, these nutrients reach the roots in a different way. The nutrients are carried to the root surface because of the swirling and unpredictable movement of the liquid (Baiyin *et al.,* 2021), which brings the nutrient particles to the roots. Recently, scientists have been looking at how the speed of the liquid carrying nutrients affects the growth of crops in hydroponics. They did experiments with different flow rates. One group of researchers found that lettuce plants grew best when the liquid flowed at a rate of 1 litre per minute, and the plants had the most nutrients in their leaves (Dalastra*et al.,* 2020).Another study used slightly salty water and found that a flow rate of 1.5 litres per minute gave the best results in terms of the weight of the plant parts, leaf size, and overall plant health (Soares*et al.,*2020).A different study looked at three kinds of lettuce and found that a flow rate of 1.5 litres per minute, with the full strength of nutrients in the liquid, made two of the lettuce types grow better (Genuncio*et al.,*2012).Lastly, some researchers tested three flow rates, and they found that lettuce plants grew the most when the liquid flowed at 20 litres per minute (Al-Tawaha*et al*., 2018).All these studies show that the speed of the liquid carrying nutrients can make a big difference in how well hydroponic plants grow. So, it's a good idea to control the flow rate to get the best results when growing vegetables in hydroponics.

CONCLUSION

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The research papers stress the importance of soilless cultivation and nutrient solutions, highlighting their ability to offer precise control over environmental conditions. This precise control, which includes monitoring pH, EC concentration, and root temperature, plays a crucial role in ensuring optimal solution quality management. This meticulous attention to detail ultimately leads to increased crop yields and improved crop quality. Therefore, accurately formulating and managing nutrient solutions is a key factor in achieving success in hydroponic crop production, as emphasized in the study.

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