Nutrient Management in Hydroponic Systems for Urban and Peri-Urban Agriculture

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ABSTRACT

Soil based agriculture systems in urban and peri-urban areas or around metro cities is facing various challenges such as rapid urbanization, industrialization, natural disaster, declining soil fertility, mineral mining and sewage water based polluted leafy vegetables etc. which are creating lot many problems. In the new era, soilless cultivation is gaining popularity all over the world and India because of efficient use of the water, fertilizers and other resources for quality vegetable production in urban and peri-urban areas. In this article historical background of soilless culture and various types of soilless culture systems their advantages and limitations are discussed. Among factors affecting soilless production systems, the nutrient solution is considered to be one of the most important determining factors of crop yield and quality. Plant nutrients, classification, their functions and essentiality for plants along with plant usable forms and critical nutrient concentration are thoroughly discussed in the article. The concept of pH of the nutrient solution and its effect on nutrient availability; relation between electrical conductivity and osmotic potential along with its effects on nutrient uptake are discussed in the article. Oxygenation in the nutrient solution is also important for root growth and overall plant growth; factors affecting nutrient solutions behaviour are also reported, emphasizing temperature; formulation and preparation of nutrient solutions considering different fertilizer sources are described as well.

Keywords: Urban Agriculture, Nutrient Management, Hydroponics, Peri-Urban Agriculture, Soilless Culture.

Introduction

The word hydroponic is derived from two Greek words, *hydro*, meaning water, and *ponos*, meaning labor (i.e., working water). The word first appeared in a scientific magazine article published in February 1937 and was authored by W. F. Gericke. Resh (1995) defines hydroponics as "the science of growing plants without the use of soil, but by use of an inert medium, such as gravel, cocopeat, oasis cube, sand, peat, vermiculite, pumice, or sawdust, to which is added a nutrient solution containing all the essential elements needed by the plant for its normal growth and development." Wignarajah (1995) defines

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hydroponics as "the technique of growing plants without soil, in a liquid culture by supplying water soluble essential nutrients". Harris (1977) suggested that a modern definition of hydroponics would be "the science of growing plants in a medium, other than soil, using mixtures of the essential plant nutrient elements dissolved in water." Jensen (1997) stated that hydroponics "is a technology for growing plants in nutrient solutions (water containing soluble fertilizers) with or without the use of an artificial medium (sand, gravel, cocopeat, oasis cubes vermiculite, rockwool, perlite, peat moss, coir, or sawdust) to provide mechanical support."Jensen defined the growing of plants without media as "liquid hydroponics" and with media as "aggregate hydroponics." Similarly related hydroponic terms are "aqua (water) culture," "hydroculture," "nutriculture," "soilless culture," "soilless agriculture," "tank farming," or "chemical culture." The growing of plants in an inorganic substance (such as cocpeat, oasis cube, sand, gravel, perlite, or rockwool) or in an organic material (such as sphagnum peat moss, pine bark, or coconut fiber) that are periodically watered with a nutrient solution should be referred to as soilless culture but not necessarily hydroponic. Hydroponics used to be considered a system where there was no growing media at all, such as the Nutrient Film Technique in vegetables.

Importance of Soilless Culture

Food security with good quality is one of the pivotal themes of the new millennium that the most urgent challenge for the agriculture sector. Further, increasing industrialization, urbanization, climate change (particularly uncertain rainfall) rapid soil erosion, degrading soil fertility, soil pollution, soil salinization, excess use of irrigation water, intensive agriculture, nutrient mining, reducing natural resources, less use of organic manures and reducing organic matter etc. are the major concerns for reducing yield and productivity of crops. Moreover, the strict dependency of agricultural practice on water availability in the age of drastic climate change (desertification) make the situation complex (Table 1). Modification in growth medium is an alternative for sustainable production and to conserve fast depleting land and available water resources. In the present scenario, soil less cultivation might be commenced successfully and considered as alternative option for growing healthy food plants, crops or vegetables (Butler and Oebker, 2006). Agriculture without soil includes hydro agriculture (Hydroponics), aqua agriculture (Aquaponics) and aerobic agriculture (Aeroponics) as well as substrate culture is considered one of the more innovative agricultural strategies to produce more from less, to feed increasing population. Among these different soilless cultivation systems, hydroponics techniques are gaining popularity because of its efficient management of resources and quality food production. Various commercial and specialty crops can be grown using hydroponics including leafy vegetables, tomatoes, cucumbers, peppers, strawberries, and many more. This article covers different aspects of soilless cultivation, their types, with more stress on nutrients required their essentiality, their functions and overall nutrient solution management.

Why Go for Soilless Cultivation/Hydroponics?

» Limited water availability and water pollution
» Severe soil degradation/ reduction in fertile soils
» Urbanization and industrialization thereby reducing area for cultivation
» High demand particularly for vegetables in urban and peri-urban area
» Environment friendly and for quality vegetable production
» Oligo-elements and bio-fortification
» Higher nutrient and water use efficiency
» Nutrient mining

Table 1: Water Use Efficiency (WUE) in Soilless Cultivation Systems of Important Crops.

Type of efficiency	Species	Crop water requirement (L kg^{-1})		
		Soilless cultivation system/ Hydroponics		Soil cultivation system*
WUE	Lettuce	1.6	Barbosa et al., 2015	76
	Hot pepper	58	Ahmed et al., 2014	110
	Sweet pepper	17	El-Sayed et al., 2015	121
	Zucchini Squash	39	Rouphael et al., 2005	97
	Muskmelon	42	Hamdy et al., 2002	170
	Spinach	8.3	Van Ginkel et al., 2017	106
	Strawberries	136	Van Ginkel et al., 2017	544
	Brassica	5.0	Van Ginkel et al., 2017	129
	Tomatoes	35	Massa et al., 2010	78

Types of Soilless Cultivation

There are different types of soilless cultivation systems as stated below and Shown in figure 1.

1. Aeroponic/fogoponics
2. Deep Water Culture (DWC)/ Deep Flow Technique (DFT)/ Floating Raft Technology (FRT
3. Drip system (recovery and non-recovery)
4. Ebb and Flow
5. NFT (Nutrient File Technique) or (Nutrient Flow Technique
6. Grow bag/Dutch Bag/other media

Aeroponics

- Most sophisticated and high-tech method
- Plants with roots are suspended in container/trails
- Nutrient are sprayed on roots with timer
- Very high nutrient and water use efficiency.
- Droplet size in aeroponic ideal 30 to 100 micron
- Needs regular monitoring/suitable for leafy & fruity veggies

Advantages of Aeroponics

- The modern aeroponics system uses a low-pressure, high-pressure, or ultrasonic fogger approach to growing fruit and vegetables.
- Higher nutrient use efficiency and higher water use efficiency (85 to 95 %)
- It permits a massive amount of plant growth/ fast growth/
- Higher yields are possible with aeroponics.
- Aeroponics requires very little space to create high levels of production.
- It takes fewer resources to produce a yield through aeroponics
- It produces healthier root systems / less disease/pest and best research tool

Limitations of Aeroponics

- High initial setup cost / expensive growing method
- Technocrat with specialty in nutrient, plant physiology climate parameters & their interactions is necessary
- Close monitoring or attention required and suitable for certain leafy vegetables.
- Power backup requires (Aeroponics system uses high pressure pumps, sprinklers and timers

Deep Water Culture (DWC)/ Deep Flow Technique (DFT)/ Floating Raft Technology (FRT)

- Suitable for leafy veggies in that roots are suspended in nutrient and oxygen rich bed
- Rectangular tank with one feet filled nutrient rich solution
- Plants are fixed on stay foam, thermacol sheet etc
- Suitable for short-term, non-fruiting like leafy greens/herbs

Advantages and Limitations of DWC

Advantages	Limitations
* Components are bed, nutrient solution, water, air pump * Suitable for almost all leafy veggies like lettuce, spinach/ Simple to set up * Fairly simple to understand * Requires fair monitoring * Maintenance cost is less * Plants grow faster and higher yield	* Fluctuations in nutrient concentration * Needs close monitoring for pH and EC of nutrient solution * Needs monitoring of water temperature ($O2$ solubility) * Air pump needs to work properly. * Mosquito and algal growth in water

Drip System (recovery and non-recovery)

- Most simple similar to conventional system
- Instead of soil, inert growing media is used
- Media: Coco peat, oasis cube, rockwool, hydrotones etc
- Growth fast and high yield used mostly for leaf and fruity vegetables

Advantages and Limitations of Drip system

Advantages	Limitations
* Similar to soil and simple to build, provides more control over nutrient & water supply growth fast, high yield and cost effective * Growing media helps to hold sufficient water * Requires fair monitoring, Low maintenance * Flexible and Low maintenance * Growth fast/ higher yield/ suitable for most crops as per growth habit	* Fair technical expertise/ pH and EC need to be monitored. Under water re-cycling: maintenance cost slight. * Under non-recovery : Waste of nutrients/water * Some growing media may have algal growth/salt hold: needs to monitor

Ebb and Flow

- Also termed as flood and drain/ popular hydroponic system due to easily built
- Delivers water, nutrients and oxygen to plant roots in floods and drain cycle
- Can be used to most leafy and fruity vegetables, simple/Reliable/easy to install/less cost
- Cucumbers, beans, tomatoes, and other medium-to-large sized plants

Advantages and limitations of Ebb and Flow

Advantages	Limitations
* Simple, easy built, not costly components required * Scalable and adaptable to different growing needs. * Resource efficient (water and nutrients)	* Dependent on electricity and a pump * Expanded systems are more complicated to build * Unstable pH and nutrient levels of the recycled solution * Getting the cycle timing right can be challenging

NFT (Nutrient Flow Technique)

- Most suitable for commercial leafy veggies production
- A shallow stream of water (film) containing nutrients will be re-circulated through pipes
- NFT channel slope and flow rate of nutrient solution are very important
- Suitable for leafy and fruity vegetables this can be the vertical or horizontal system which easily increases the growing area

Advantages and Limitations of NFT

Advantages	Limitations
* Production and productivity is higher * Easy to build, maintain and inspect for any root disease * High water and nutrient use efficiency * Oasis cube, coco-chips, rockwool etc * Oxygenation is optimum recirculation * Suitable for all areas may be vertical or horizontal farming	* Monitoring of pH and EC required. * Initial cost is very high particularly for NFT channels * Roots can block the flow of nutrient solution * Not suitable for crops having tap root systems like carrots/ raddish * Power failure can cause problems

Growing Media

There are different kinds of growing media (figure 2) are used for mechanical support in soilless cultivation. Further different types of media are suitable for specific kinds of soilless cultivation system adopted.

Criteria for Selecting Media

- pH/EC/ More CEC should be optimum and serve as the reservoir of plant nutrients.
- Sufficiently firm enough to encourage or support the plants.
- Provides aeration for the exchange of gases/O2.
- Should not shrink or expand easily, should have good drainage and porosity.
- Should be easily available and economical and should be sterilized easily.
- Free from pathogens, pests, weed and seeds etc. and should not react with nutrient elements
- Must be reusable and restrict algal growth

Advantages of Soil less Cultivation

Advantages	Limitations
* Higher water and nutrient use efficiency * Less growing period and continuous Production * Require less space * Higher productivity and higher yields * Good quality of produce due to controlled condition * Less depend on seasonality * No severe disease and pest attack * Do not require tillage practices, weeding, soil fertilization crop rotation	* Higher initial cost/ Monitoring of pH and EC Necessary and effective to control nutrient solutions * Higher technical knowledge More periodic and routine work Efficient electrical systems * Needs to monitor microbial diseases through water

Reference: Alfredo Aires (http://dx.doi.org/10.5772/intechopen.73011)

Nutrient Management in Hydroponic Systems

Arnon and Stout (1939) described three requirements that an element had to meet to be considered essential for plants. There are a total of 17 essential nutrients along with their critical nutrient concentration and plant usable forms are stated in Table 2.

1. Plant unable to complete its life cycle without that nutrient
2. Element is essential for the plant when it is having a specific role or the function of the nutrient is specific which cannot be replaced by other.
3. The element is having direct role in metabolism.

Primary nutrients	Secondary nutrients	Micronutrients
Carbon, hydrogen, oxygen, nitrogen, phosphorus, and potassium	Calcium, Magnesium and Sulphur	Iron, manganese, zinc, copper, boron, molybdenum, chlorine, nickel

Table 2: Concentrations of Nutrients in Higher Plants (on dry weight tissue basis)

Sr.No.	Nutrient	Plant usable form	Concentration in plants (%)	Ppm
1	Carbon	$CO2$	45	450000
2	Hydrogen	$H2O$	6	60000
3	Oxygen	$H2O$, $O2$	45	450000
4	Nitrogen	$NH4$, $NO3$	1.5	15000
5	Phosphorus	$H2PO4$, $HPO4$	0.2	2000
6	Potassium	K^{+}	1	10000
7	Calcium	Ca^{2+}	0.5	5000
8	Magnesium	Mg^{2+}	0.2	2000
9	Sulphur	$SO4^{2-}$	0.1	1000
10	Iron	Fe^{2+}, Fe^{3+}	0.01	100
11	Manganese	Mn^{2+}	0.005	50
12	Zinc	Zn^{2+}	0.002	20
13	Copper	Cu^{2+}	0.0006	6
14	Molybdenum	$MoO4$	0.1	0.00001
15	Boron	$H3BO3$	20	0.002
16	Chlorine	Cl-	0.01	100
17	Nickel	Ni2+		

Function and deficiency symptoms of essential nutrients.

Nitrogen:

- Component of chlorophyll, enzyme, amino acids and protein
- Encourages vegetative growth & deep green colour
- Enhances plumpness in cereal crops and succulence in crops
- Role in utilization of carbohydrates

Phosphorus

- Energy storage & transfer (1 ATP/ADP= 1200 cal/mole)
- Cell division, cell development, root lengthening, seed and fruit development, early maturity and early ripening
- Component of nucleic acid, co-enzyme, nucleotides, phospholipids, phosphoproteins & sugar phosphates
- Phytic acid/ phytin- storage form of P in seeds

Potassium

- More than 80 plant enzymes require K for activation
- Synthesis of ATP, translocation of carbohydrates
- Synthesis of amino acids, proteins, chlorophyll
- Enhance resistance against moisture stress by regulating opening & closing of stomata and disease resistance
- Affects the rate of transpiration & water uptakes, produces strong stiff straw which inhibit lodging in crops

Calcium

- Immobile in plant, Constituent of cell wall, require for cell elongation & division
- Activation of enzymes, role in structure & permeability of cell membrane
- Enhance uptake of NO3-N

Magnesium

- Component of chlorophyll (15-20% Mg present in Chlorophyll)
- Structural component of ribosome- protein synthesis
- Imparts dark green colour/ Photosynthesis/ glycolysis
- Role in oil seed crops, Helps in transport of P
- Synthesis of carbohydrates, fats & vitamins

Sulphur

- Component of protein (S- containing amino acids cystine, cysteine & methionine),
- Requires for chlorophyll synthesis, Important role in oil synthesis
- Requires for the synthesis of co-enzymes A
- Involved in synthesis of fatty acids & component of ferridoxin

Iron

- Absorbed by plants as $Fe2+$ & $Fe3+$, activation of enzymes
- Component of porhyrin, cytochromes, hames, hematin, ferridoxin, ferrichrome and haemoglobin (imp. In photosynthesis & respiration)
- 75% of Fe is associated with chloroplast, required for synthesis of chlorophyll
- Important component of nitrogenase enzyme essential for N2 fixation

Manganese

- Anonymous role like Fe Involvement in photosynthesis for evolution of O2
- Oxidation-reduction reactions and Enzyme activation (citric acid cycle)
- Mn can substitute for Mg in phosphorylating & group transfer (ETC
- Manganese helps in chlorophyll formation, Important in nitrogen metabolism

Zinc

- Involved in many enzymatic activities
- Zn required for synthesis of tryptophan-amino acid necessary for the synthesis of growth hormone
- Component of synthetic & natural organic complexes

Copper

- Important role in enzyme activity acceleration
- Protein & carbohydrate metabolism
- Helps in utilization of Fe during chlorophyll synthesis
- Synthesis of complex polymers like lignin & melanin. Indirect effect on nodule formation

Boron

- Primary role in Ca metabolism (Boron increases the solubility and mobility of Ca in plant
- Cell development in meristematic tissue, Proper pollination, fruit & seed set
- Translocation of sugars, starches, N and P
- Synthesis of amino acids and proteins, nodule formation, regulation of carbohydrate
- Pollen germination & pollen tube growth

Molybdenum

- Essential component of nitrate reductase enzyme which catalyses the conversion of NO3 to NO2
- Structural component of nitrogenase enzyme involved in N2 fixation by Azatobactor
- Role in absorption and translocation of Fe
- Involvement in protein synthesis

Chlorine

- Osmotic regulation & cation neutralization
- Maintaining leaf turgor
- Cl acts a co-factor in Mn containing O2 evolution for photosynthesis
- Cell elongation and stomata opening
- In absence of Cl photosynthesis rate reduced

Management of Nutrient Solution in Hydroponic System

1. pH and its management
2. EC and its management
3. Composition of nutrient solution
4. Temperature of nutrient solution
5. Oxygenation of nutrient solution

pH and its Management

The pH value indicates the relationship between the concentrations of free ions H+ and OH- present a solution and ranges between 0 and 14. Changing the pH of a nutrient solution affects its composition, bioavailability and speciation (Table 3) (Distribution of elements among their various physical and chemical forms like chelates, soluble complexes, ion pairs etc.).

Table 3: Nutrient Responses to change in pH.

Sr. No.	Nutrient	Responses to change in pH
1	Nitrogen	* In nutrient solution only NH3 forms a complexes with H+. * pH range between 2 and 7: NH3 is completely present as NH4. * Increasing the pH above 7.0, the concentration of NH4 decrease, with the concentration of NH3 augments (De Rijck G. & Schrevens, E. (1999) * At pH 8.5: Ammonia oxidation rate increases compared to nitrite oxidation rate that resulting in the accumulation of NO2 to toxic or harmful levels to plants.
2	Phosphorus	* Plant usable forms of phosphorus are strongly influenced by solution pH. * At pH 5 largest amount of available forms are HPO42- and H2PO4- ions * In acidic and alkaline solutions the concentration of available phosphorus decreases significantly. * At alkaline pH chemical available forms get complexed with Ca2+

3	Potassium	* Potassium is almost present as free ion in a nutrient solution with pH values from 2 to 9 but only small amount of K^+ forms a soluble complex with $SO4^{2-}$ or can be bound to Cl- (De Rijck G. & Schrevens, E. (1998).
4	Calcium	* Availability is at wider pH range but the presence of other ions interferes with their availability due to the formation of insoluble complexes. * As water naturally contains HCO3, this ion get converted into CO_3^{2-} when the pH is higher than 8.3. * When pH is less than 3.5, the H2CO3 and CO2 becomes equilibrium with each other.
5	Fe, Mn, Zn and Cu	* At pH higher than 6.5: Fe, Mn, Zn, Cu and boron becomes unavailable. (Tyson, 2007) * Boron is taken up by plants as boric acid and availability is high at acidic range or near neutral but not > 7.0.

Management of pH:

- The changes in the pH of a nutrient solution largely depend on the difference in the intensity of nutrient uptake by plants. Higher anion uptake than cation for example, uptake of NO3-N causes the plant to excrete OH- and HCO3- anions to balance the charge that increases pH value which is termed as physiological alkalinity (Marschner, 1995).
- Many times use of ammonium as N source in the nutrient solution regulates the pH and therefore nutrient availability is ensured. Breteler & Smit (1974) reported that ammonium depressed the pH of nutrient solution even in the presence of nitrate.
- The pH adjustment mostly requires to reducing the pH by adding acids. Regulation of pH is normally carried out by using nitric, sulphuric or phosphoric acid, and such acids can be used either individually or combined. The pH is closely related to the concentration of HCO3- and CO32-; when an acid is applied, the CO32- ion is transformed to HCO3- , and then HCO3- is converted into H2CO3.

Electrical conductivity:

The concentration of ions in solutions determines the growth, development and production of plants (Steiner, 1961). The nutrient salts dissolved in water exert a pressure called osmotic pressure (OP) which is colligative property of solution containing nutrients and it is dependent on the amount of soluble salts dissolved salts. The solutes present in nutrient solution reduces the free energy of water. An EC measurement can be a good indicator for availability of nutrient ions in the root zone from nutrient solution (Nemali and Van Lersel, 2004). The dissolved ion related to EC are Ca2+, Mg2+, K+, Na+, H+, NO3-, SO42-,Cl-,HCO3-,OH etc. EC or total soluble ions are specific for each crop and dependant on environmental conditions like temperature and humidity (Sonneveld and Voogt, 2009) (table 4 and 5). Optimum EC values for most of urban agriculture or hydroponic system ranges from 1.5 to 2.5 dSm-1 while higher EC hinders or reduces water availability and nutrient uptake.

Management of Electrical Conductivity

- The change in electrical conductivity appears due to the uptake of water and nutrients by plants.
- Hence increase and decrease in the concentration of some ions in nutrient solution is observed during crop growth.
- It is observed that iron concentration decreased rapidly while that of Mg2+, Ca2+, and Cl- increased further, concentration of K+, Ca2+ and SO4 2- did not reach critical levels
- Instead, in an open system with recirculation of nutrient solution, an increase in the EC value due to the accumulation of high levels of some ions like bicarbonates, sulphates and chlorides is observed (Zekki et al. 1996). So, the recycling of nutrient solution represents a point of discussion.
- Moreover, the substrates can retain ions and consequently the EC increases. To reduce the salt accumulation in substrates, controlled leaching with water of good quality is an alternative (Ansorena, 2004).
- The use of mulching with polyethylene or polypropylene sheet reduces water consumption, increases the calculated water use efficiency and decreases the EC of the substrate; so the mulching is an alternative to control of EC too (Farina et al., 2003). (Tanji, 1990)

Table 4: Nutrient solutions and salinity levels as per crops.

Salinity group	Threshold EC (dS m^{-1})	Crops
Sensitive	1.4	Lettuce, carrot, strawberry, onion
Moderate sensitive	3.0	Broccoli, cabbage, tomato, cucumber, radish, pepper

Table 5: Optimum EC and total soluble Salts in Nutrient Solution

Sr.No.	Crop	Optimum EC (dSm^{-1})	TSS ($mg\ L^{-1}$)
A. Leafy Greens			
1	Lettuce	0.8 to 1.2	550 t0 800
2	Spinach	1.8 to 203	1260 to 1610
3	Celeray	1.8 to 2.4	1260 to 1680
4	Basil	1.0 to 1.6	700 to 1120
5	Mint	2.0 to 2.4	1400 to 1680
6	Pok –choy	1.5 to 2.0	10501400
B. Fruity vegetables			
1	Cucumber	1.7 to 2.65	1190 to 1750
2	Peeper/capsi-cum	1.8 to 2.8	1400 to 2000
3	Tomato	2.0 to 4.0	1400 to 2800
4	Broccoli	2.8 to 3.5	1960 to 2450
5	Cabbage	2.5 to 3.0	1750 to 2100
6	Zuccini	1.8 to 2.4	1860 to 1680

Composition of Nutrient Solution

Composition of nutrient is generally depends upon the requirement of crop. When a nutrient solution is applied continuously, plants can uptake ions at very low concentrations. So, it has been observed that a high proportion of the nutrients are not used by plants or their uptake does not impact the production.

No adverse impact was found on growth, fruit yield and fruit quality of tomato when concentration of nutrients is reduced by 50% (Siddiqi et al. 1998). However, it is also observed that in particular situations, too low concentrations do not cover the minimum demand of certain nutrients. On the other hand, high concentrated nutrient solutions lead to excessive nutrient uptake and therefore toxic effects may be expected.

There are different essential nutrient recipes developed by various authors as stated in table 6. Further , Fertilizers containing essential nutrients commonly used for nutrient solution is also stated in table 7.

Table 6: Essential Mineral Element Nutrient Concentration according to various authors

Nutrient	Hoagland and Arnon (1938)	Hewitt (1966)	Cooper (1979)	Steiner (1984)
mg L^{-1}				
Nitrogen	210	168	200-236	168
Phosphorus	31	41	60	31
Potassium	234	156	300	273
Calcium	160	160	170-185	180
Magnesium	34	36	50	48
Sulphur	64	48	68	336
Iron	2.5	2.8	12	2-4
Copper	0.02	0.064	0.1	0.02
Zinc	0.05	0.065	0.1	0.11
Manganese	0.5	0.54	2.0	0.62
Boron	0.5	0.54	0.3	0.44
Molybdenum	0.01	0.04	0.2	Not considered

Table 7: Fertilizers containing essential nutrients commonly used for Nutrient Solution

Fertilizers	Formula of Nutrient Salt	Nutrient Content	Solubility g L^{-1} at $20^{0}C$
Calcium nitrate	$Ca(NO_3)_2.5H_2O$	N: 15.5; Ca:19	1290
Potassium nitrate	KNO_3	N:13; K:38	316
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	N:11; Mg:9	760
Ammonium nitrate	NH_4NO_3	N:35	1920
Monopotassium phosphate	KH_2PO_4	P:23; K:28	226
Monoammonium phosphate	$NH_4H_2PO_4$	N:12, P:60	365
Potassium sulphate	K_2SO_4	K:45; S:18	111
Magnesium sulphate	$MgSO_4.7H_2O$	Mg: 10; S:13	335
Ammonium sulphate	$(NH_4)_2SO_4$	N:21;S:24	754
Potassium chloride	KCl	K:60; C:48	330

4. Temperature of Nutrient Solution

- At high temperatures of the nutrient solution an increased vegetative growth to a greater extent than desirable is observed, which reduces fructification and may enhance pest attack. The temperature of the nutrient solution drastically affects nutrient availability, water and nutrient uptake and translocation of nutrients within the plant system.
- In tomato plants, rates of water and nutrient uptake by roots (which varied depending on solar radiation) were studied by Falah et al.,2010 and reported that high solution temperature (350C) in the long-term, solubility of oxygen was reduced, while enzymatic oxidization of phenolic compounds in root epidermal and cortex tissues were stimulated, but nutrient concentration in root xylem sap diminished, and the root xylem sap concentration of N, K, Ca became lower than those in the nutrient solution (Falah et al., 2010).
- Leaf length, leaf number and total fresh and dry biomass weights per plant were higher in plants grown at elevated temperatures, with optimum growth being recorded at 28 °C (Nxawe et al., 2009). Graves (1983) observed that at temperatures below 22 °C the dissolved oxygen in the nutrient solution is sufficient to cover the demand of this element in tomato plants.

Oxygenation of Nutrient Solution

The oxygen content is also affected by growing media. The consumption and solubility of oxygen increase when the temperature of nutrient solution increases (table 8) thereby enhancing relative concentration of CO2 in the root environment (Morard & Silvestre, 1996). Further, decrease in oxygen content below 3 or 4 mg L^{-1} of inhibits root growth and produces changes to a brown colour, which can be considered the first symptom of oxygen lack (Gislerød and Adams 1983).

Nonetheless, substrates under long cultivation periods usually present increase of organic matter content and microorganism activity, which could lead to an increase in the competition for oxygen in the root environment. Yet, roots are densely matted within the substrate, which alters diffusion and supply of oxygen (Bonachela et al., 2010). Generally 3% H2O2 @ 1 ml per litre was found beneficial for profuse root growth, nutrient uptake, boos plant growth, kills bacteria and also helps to fight root rot and fungi.

Table 8: Solubility of Oxygen in Water as Influenced by Temperature

Temperature(^{0}C)	Oxygen solubility (mgL^{-1} of pure water)
15	10.08
20	9.09
25	8.26
30	7.56
35	6.95
40	6.41

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