Optimisation of advanced nutrient solutions for escalating crop production under hydroponics systems: A comprehensive review

Abstract

Hydroponic farming has the potential to be a viable solution to problems related to conventional agriculture, such as deteriorated soil and limited water supply. Hydroponic farming may significantly increase crop yields while preserving the resources by cultivating various plants in a soilless medium using a precisely calculated ~~nutrients~~nutrientsolution. This review ~~paper~~ examined the functions of nutrient solutions which are being used under hydroponic farming, emphasizing the formulations, preparationand utilization of these solutions for growing crops. A crucial part of hydroponic systems is the nutrient solution which offers the plants both the macro and micronutrients as they are required for plant growth and development.Nutrient management in hydroponics is critical for making the optimum use of crop nutrients while minimizing the environmental impact. Total dissolved solids, pH and electrical conductivity are the three most important components in nutrient~~s~~ management ~~components~~ in soilless cultivation. Nutrient availability is influenced by pH, however,pH of 5.8-6.5 is considered as the best range for ~~hydroponic based~~hydroponic-based productions. The optimal range for electrical conductivity (EC) is 1.5 to 2.5 dS/m. The optimal range for total dissolved solids (TDS)for successful hydroponics growing ranges from 800–1500 ppm.For avoidingthe toxicities or ~~nutritional based~~nutritional-based deficiencies, any fluctuations in pH,EC and TDS can lead to yield retardation, and therefore, these parameters should be monitored on a daily basis for successful hydroponics goal.Hence, the review paper ~~emphasis~~emphasizeson different fertilizer ~~dosages~~dosagecalculations for hydroponic systems. Although different crops require different amounts of nutrients, so itbecome essential to analyse, modify and apply the right nutrientsdoseat right crop stage. Ultimately, the review provides ~~a~~ better insights and understanding of different nutrient formulations opted for hydroponically based crops such as leafy vegetables and herbs.In a hydroponic environment, these formulations areproduced to fulfil the nutritional demand forensuring healthy development and ~~boost~~boostingyields.

Keywords – Hydroponics, total dissolved solids, nutrients formulations, fertilizers, crop, environment, sustainability

Introduction

In relation to sustainability objectives, it is critical to evaluate appropriate tools to support the shift to a resilient agricultural model that strikes a balance between sustainability and growth. Prioritizing environmental sustainability and efficient production is necessary to find answers to the expanding global population as well as issues with food and water security[1]. It is highly challenging for farmers everywhere to supply the demand for food while also addressing the deteriorating conditions of the land spurred on by intensification. To maintain a sustainable food supply, the focus must move from boosting crop output to creative and precise agricultural methods. Furthermore, the projected climatic scenarios offer a significant danger, especially in areas that rely largely on weather and seasonal fluctuations. Soil deterioration, water contamination, and depleted soils are existing problems and are predicted to get worse in the future [2]. A potential approach to overcome these issues and increase crop production while improving food security is to grow crops through hydroponics which involves growing plants in nutrient solution and a soilless growth media in a controlled environment.Hydroponic farming has several benefits over traditional farming. The effective use of water in hydroponics is one of its main benefits. When it comes to sustainable agriculture, hydroponics has an advantage since it uses less water, produces larger yields, and gives producers more control over the environment[3]. Hydroponics is a sustainable and viable approach for fulfilling rising food production demands. Plants in a hydroponic system can produce 20-25% more than plants in a soil-based system, with output that is 2-5 times greater. Moreover, modern technology makes it possible to regulate agricultural water, fertilizer, temperature, and insect conditions more effectively, which raises output and profits. Hydroponic plants are known for their high nutritional content, quick harvesting times, and constant excellent quality[4].

With this approach, the nutrient solution is continuously supplied ~~in close proximity to~~near the plant's root zone and recycled in a closed loop, resulting in increased plant nutrient absorption and increased crop output. Ion-selective electrodes are used more quickly and effectively in the monitoring of hydroponic nutrient solutions through computerization, connectivity, and the internet of things in hydroponics. In hydroponic farming, the use of growth medium reduces the possibility of soil-borne infections. Artificial media, such as sand, gravel, rockwool, vermiculite, perlite, ~~peatmoss~~peat moss, or sawdust, are typically used in hydroponics to absorb nutrients from solution when it is in circulation and to deliver them to the plant roots when the nutrient solution circulation stops in hydroponic systems.

The nutrient solution is an essential component of hydroponic systems, promoting plant growth and development without the need for soil. Plants receive the vital macro- and micronutrients required for their metabolic activities from this precisely adjusted solution [5]. Hydroponics provides an accurate and effective technique of nutrient delivery, increasing plant absorption and usage by supplying nutrients directly to the plant roots in a controlled environment. In hydroponic farming, it is crucial to control the nutrient solution properly as it affects both water use efficiency (WUE) and nutrient use efficiency (NUE). The nutrient solution in hydroponics may be adjusted to maximize plant output while reducing resource waste through innovative approaches and monitoring methods, making it a crucial area of study for enhancing agricultural sustainability.This review discusses nutrient solutions in hydroponics.

Nutrient solution and it's composition

One of the main factors influencing hydroponic production systems and affecting crop output and quality is considered to be the nutrient solution. A nutrient solution in hydroponics is a type of liquid mixture that supplies plants with all the nutrients they require for proper growth and development. It includes dissolved essential mineral components in water. This is the only source of nutrients for plants produced in hydroponic systems since they are not dependent on soil to absorb nutrients. It is considered that the majority of plants require the following 17 elements: iron, copper, zinc, manganese, molybdenum, boron, chlorine, nickel, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, and hydrogen [6]. ~~With the exception of~~Except for carbon (C) and oxygen (O), which are supplied from the atmosphere, the essential elements are obtained from the growth medium.

Among the minerals, N, P, and K are the most decisive elements in plants. An essential step in producing crops in hydroponic systems involves developing a nutrient solution which provides a suitable ratio of ions for plant growth and development. All the components required for plant growth are given through various chemical combinations [7]. Six essential nutrients are often present in nutritional solutions: N, P, S, K, Ca, and Mg. As a result, Steiner developed the concept of an ionic mutual ratio, which is predicated on the mutual ratios of the cations K+, Ca^{2+}, and $Mg^{2+}$and the anions NO_3^-, $H_2PO_4^-$ and SO_4^{2-}. This type of interaction involves more than simply the total amount of each ion in the solution. It also involves the quantitative relationships that keep the ions together and if these relationships are not appropriate, plan performance may suffer[8]. Thus, it is difficult to provide one ion without adding a counter ion due to the ionic balancing limitation. A change in one ion's concentration involves the presence of either a complementary change for additional ions with the same charge, a comparable change for ions with the opposite charge or both[9]. Since various species have varying demands, the nutrients must be specific to each crop and indicate the crop's intake of each element.There are two types of nutrient solutions: liquid and powdered (dry),~~.~~b~~B~~oth are widely applied in hydroponic cultivation. There are several significant distinctions between the two, even though they both provide nutrients to plants.For hydroponics, liquid nutrient solution is pre-mixed. It contains all of the vital components, which are concentrated and dissolved in water. Measure the amount prescribed per the instructions before using liquid nutrition solution. After that, put it in the hydroponic reservoir. This is a simple approach that doesn't take much labour or prior knowledge to regulate nutritional levels.

There are several varieties of dry fertilizer available. Similar to liquid fertilizer, premade blends are available. The proper quantity of this sort of fertilizer must be dissolved into reservoir water. Multipart mixes are also available. Dry fertilizers need mixing ~~together~~ of a number of different powders. These usually consist of a calcium nitrate mix and a standard NPK mix. Certain component combinations of dry fertilizers are available. These consist of a variety of powders that must be blended. These do demand a bit more effort and knowledge. Nevertheless, they continue to be a cost-effective and efficient way to nourish plants. Certain plant growth phases can also be targeted using hydroponic fertilizers and nutrients. There are formulae for seed starters, for example. Mixtures for the vegetative stage are created as plants grow. Bloom boosters are available for older plants to help them reach the blooming stage.

Table 1.Estimated content in plants, functions in plants, and sources of vital nutrients that plants are able to acquire

Nutrient (chemical symbol)	Approximate content of plant (% dry weight)	Roles in plant	Source of nutrient available to plant
Carbon (C), hydrogen (H), oxygen (O)	90+%	Components of organic compounds	Carbon dioxide (CO_2) and water (H_2O)
Nitrogen (N)	2–4%	Enables the formation of proteins and enzymes and supports the development of healthy leaves.	Nitrate (NO_3^-) and ammonium (NH_4^+)
~~Sulfur~~Sulphur (S)	0.50%	Helps with protein synthesis and enzyme activity.	Sulphate (SO_4 ²-)
Phosphorus (P)	0.40%	Plays a vital part in the development of flowers and roots.	Dihydrogen phosphate ($H_2PO_4^-$), Hydrogen phosphate (HPO_4^{2-})
Potassium (K)	2.00%	Assists in disease resistance and general plant health.	Potassium (K^+)
Calcium (Ca)	1.50%	Essential for cell wall structure and stability.	Calcium (Ca^{2+})
Magnesium (Mg)	0.40%	Involved in chlorophyll production.	Magnesium (Mg^{2+})
Manganese (Mn)	0.02%	Involved in the activation of	Manganese (Mn^{2+})

		enzymes and aids in the resilience of plants under stress.	
Iron (Fe)	0.02%	Vital for the synthesis of chlorophyll and the transfer of energy among cells.	Iron (Fe^{2+})
Molybdenum (Mo)	0.00%	Essential for the fixation of nitrogen and for the conversion of nitrate to ammonia.	Molybdate (MoO_4^{2-})
Copper (Cu)	0.00%	Helps to produce lignin, which fortifies cell walls.	Copper (Cu^{2+})
Zinc (Zn)	0.00%	Crucial for root development and growth hormone generation.	Zinc (Zn^{2+})
Boron (Bo)	0.01%	Impacts the metabolism of carbohydrates and cell division.	Borate (Bo^{3-})
Chlorine (Cl)	0.1–2.0%	Involved in photosynthesis and osmotic regulation.	Chlorine (Cl-)
Nickel (Ni)	0.000005–0.0005%	Involved in nitrogen	Nickel (Ni^{2+})

		metabolism, biological nitrogen fixing, and some enzymes' components	

Source:(Sánchez and Gioia,2023) [10]

Nutrient management in hydroponics

The objective of nutrient management is to use crop ~~nutrient~~ nutrientsefficiently without causing any adverse environmental effects and enhancing ~~the~~ productivity. Nutrient management is an essential step in hydroponics. The three key factors to consider while managing nutrients in soilless culture are total dissolved solids, pH, and electrical conductivity**.**

1. **pH:** The pH scale indicates how basic or acidic the solution is at the time of analysis. The neutral value is 7, and the range is 0 to 14. A nutrition solution's pH affects how readily available the nutrients are, thus it should be kept within the ideal range. For hydroponic cultivation, the ideal pH range for ~~nutrients~~ nutrientsolutions is 5.8 to 6.5[11]. Nutrient deficiencies or toxicity symptoms may appear if the pH range is either greater or lower than the recommended range. Certain crops have varying pH levels.

   pH Management: pH buffer solution, which typically comes in pH 4, 7, or 10, is used to calibrate a pH meter probe. It is usually advisable to monitor pH when the EC has reached the ideal level. Set the desired value of EC, after that make sure to first set the solution's desired electrical conductivity (EC) value. Following that, use a buffer solution to calibrate the pH meter probe. The nutrition solution should be well mixed and give the reading some time to stabilize which might take a few minutes. If the pH value is high, gradually add phosphoric acid, citric acid, vinegar, or use ~~pH~~a ~~lowering~~ pH-loweringproduct. Repeat until the pH reaches the ideal range and wait for a few minutes in between additions. If the pH is low, slowly add potassium hydroxide, potassium carbonate, or a ~~pH increasing~~pH-increasing product and continue adding until the pH reaches the required level. Finally, rinse and preserve the pH meter probe in cleaning fluid for future use.

2. **Electrical conductivity:**In hydroponics, electrical conductivity (EC) measures the concentration of nutrients in water or the salinity of the nutrient solution. EC is essential for optimal plant growth since insufficient or excessive nutrients could negatively impact plants.For hydroponics, the ideal EC range is 1.5 to 2.5 dS/m. Nutrient motion pressure will be prevented if EC is greater than the ideal range, and plant health will be negatively impacted if EC is lower than the ideal range[12].

   Electrical conductivity Management: An EC meter is often used to measure the EC of a nutritional solution. The EC meter's calibration is done using a buffer solution. Each buffer solution has a unique EC, which is typically 1.41 mS/cm. To calibrate an EC meter, place the probe in the buffer solution and adjust the knob to the appropriate EC. To effectively maintain a nutrition solution's electrical conductivity (EC), some steps should be taken. ~~Prior to~~Before adding fertilizer, fill the nutrient tank with tap or filtered water and follow the instructions provided by the manufacturer After that, use a buffer solution to calibrate the probe of the EC meter. Allow the reading to stabilize, which might take a few minutes, and make sure the nutritional solution is properly mixed. If the EC value exceeds the optimal level, dilute the solution with more water and repeat the stabilization process. If the reading is below the ideal level, add nutritional concentrate and repeat the stabilization procedure. Finally, rinse the EC meter probe with tap water and preserve it in probed-cleaning solution for further use.

3. **Total Dissolved Solids (TDS):** The cumulative measurement of inorganic salts, minerals, and other dissolved materials found in the water and fertilizer solution used in hydroponics is known as total dissolved solids, or TDS. These substances include micronutrients like calcium, magnesium, iron, and other elements as well as necessary nutrients like potassium, phosphorus, and nitrogen. Usually, TDS is expressed in parts per million (ppm). Monitoring TDS levels in hydroponic systems is crucial to maintaining good operation and overall performance. The optimal TDS range varies by plant species, development stage, and nutrient solution composition. For the majority of hydroponic crops, a TDS range of 800 to 1500 parts per million (ppm) is ideal.

TDS Management: TDS is measured by TDS meter for a solution. A high TDS result implies a greater concentration of dissolved salts and minerals. This may result in nutrient locking, which could lead to poor development of plants and experience nutrient shortages. High TDS could potentially be a sign of hazardous substances or components. To lower the TDS, use RO water with lesser TDS. In case of low TDS, dilute the solution with fresh water or add extra nutrients which will help in increasing the TDS.Finally, to achieve optimal crop nutrient use, boost output, and avoid negative environmental consequences, hydroponics requires good nutrients management. Maintaining ideal nutrient levels for plant development requires careful monitoring and adjustment of pH, electrical conductivity (EC), and total dissolved solids (TDS) [13].

Table 2. Optimum range of electrical conductivity EC, TDS and pH values for hydroponiccrops

Crops	EC (mS/cm)	pH	TDS (ppm)
Tomato	2.0 to 4.0	6.0 to 6.5	1,400 - 3,500
Spinach	1.8 to 2.3	6.0 to 7.0	1,250 - 1,600
Strawberry	1.8 to 2.2	6.0	800 - 1,000
Lettuce	1.2 to 1.8	6.0 to 7.0	550 – 850
Cabbage	2.5 to 3.0	6.5 to 7.0	1,750 - 2,100
Basil	1.0 to 1.6	5.5 to 6.0	700 - 1,150
Bell peppers	1.8 to 2.8	6.0 to 6.5	1400-2000
Rose	1.5 to 2.5	5.5 to 6.0	1050-1750
Mint	2.0 to 2.4	5.5 to 6.0	1400-1680
Capsicum	1.8 to 2.2	6.0 to 6.5	1260-1540

Source:(Jamie ,2023and Hydroponics South Africa ,2024)[14,15]

Fertilizer calculation

Calculating Fertilizer Dose for Nutrient Solutions

In hydroponic farming, maintaining optimal nutrient levels is crucial for plant growth and development. To achieve this, precise estimations of fertilizer dose are required. Further, it is discussed about the procedure to determine the appropriate amounts of fertilizer for various essential nutrients while accounting for desired elemental values and specific conversion factors.

- **Determining the Target Elemental Values**:Calculating fertilizer doses begins with identifying the target ~~elements ~~elementvalues for the nutrient solution. To achieve the desired concentrations, this often involves assessing the water's existing nutrient levels and calculating how much more is required.

- **Compatibility of fertilizers**: It is important to stick to certain standards ~~in order to~~to ensure that fertilizer salts in a hydroponic system are compatible. One standard procedure is to divide fertilizer salts into several stock tanks, each holding certain fertilizer kinds that work well together.

- **Nutrient Source Order:**There is a certain order that must be followed for nutritional sources ~~in order to~~to prevent imbalance and guarantee that plants can absorb nutrients efficiently. This sequence is often based on the importance of each nutrient alongside how well it complements the other nutrients in the mixture.

- **Calculating Fertilizer Dose:** When dealing with fertilizer components specified in different formats on labels, it is important to examine the labels for correct nutrient levels and to be aware of conversion factors. Each nutrient source has a few stages involved in determining the fertilizer dose.
  1. Calculate the required amount of fertilizer by using the target elemental value.
  2. Determine how much the fertilizer source added in any additional components. The calculated dosage should be adjusted for each injector ratio (stock solution concentration) and stock tank volume.

Overall, in hydroponic farming, determining the appropriate fertilizer dosage is essential for maintaining ideal nutrient levels. This procedure involves finding out the desired elemental values, making sure fertilizers are compatible, following to a certain nutrient source sequence, and calculating fertilizer dose. It's essential to take conversion factors into account and modify the dose according to the injector ratio and stock tank amount[16].

Calculating Fertilizer Amounts for a Tomato Nutrient Solution

Target Elemental Values:

- Calcium (Ca): 104 ppm
- Magnesium (Mg): 40 ppm
- Phosphorus (P): 47 ppm
- Potassium (K): 144 ppm
- Nitrogen (N): 90 ppm
- Sulfur (S): 116 ppm
- Chloride (Cl): 89 ppm

Given Information:

- Stock Tank Volume: 100 L
- Injector Ratio: 1:200

Steps to Calculate Fertilizer Amounts:

1. **Calcium (Ca)**
    - Use calcium nitrate (19% Ca).
    - Target: 104 ppm
    - Formula: Target ppm / %Ca in Calcium Nitrate
    - Calculation: 104 mg/L/0.19=547 mg/L calcium nitrate
    - Adjust for stock tank volume and injector ratio.
    - Result:
      547 mg/L×100 L×200 (injector ratio)/1000 mg/g=10.94 g calcium nitrate

Utilize 19% calcium nitrate to reach the desired calcium level of 104 ppm. The required quantity is 547 mg/L, which may be found by dividing the desired ppm by the calcium nitrate percentage (0.19). For your specific injector ratio and stock tank capacity, adjust this amount.

So, we would require about 10.94 g of calcium nitrate for a 100 L stock tank with an injector ratio of 200.

2. **Magnesium (Mg)**
    - Use magnesium sulphate (9.7% Mg, 13% S).
    - Target: 40 ppm
    - Formula: Target ppm / % Mg in Magnesium sulphate
    - Calculation: 40 mg/L/0.097=412 mg/L magnesium sulphate
    - Adjust for stock tank volume and injector ratio.
    - Result: 412 mg/L×100 L×200 (injector ratio)/1000 mg/g=8.24 g magnesium sulphate

    Magnesium sulphate (9.7% Mg, 13% S) is used in hydroponic fertilizer solutions to reach a target magnesium (Mg) content of 40 ppm. Target ppm divided by the percentage of Mg in magnesium sulphate is the formula used to determine the required quantity of magnesium sulphate. In this instance, the magnesium sulphate content is 412 mg/L (40 mg/L divided by 0.097). The injector ratio and stock tank volume should be taken into account while calculating this quantity. For instance, the needed amount of magnesium sulphate for a 100-liter stock tank with a 200-injector ratio would be 8.24 g.

3. **Phosphorus (P)**
    - Use monopotassium phosphate (22.7% P, 28.7% K).
    - Target: 47 ppm
    - Formula: Target ppm/ % P in Monopotassium sulphate
    - Calculation: 47 mg/L/0.227=207 mg/L monopotassium phosphate
    - Adjust for stock tank volume and injector ratio.
    - Result: 207 mg/L×100 L×200 (injector ratio)/1000 mg/g=4.14 g monopotassium phosphate

    Monopotassium phosphate (22.7% P, 28.7% K) is used in hydroponic fertilizer solutions to get a target phosphorus (P) content of 47 ppm. The desired ppm divided by the percentage of P in monopotassium phosphate is the formula used to determine the required quantity of monopotassium phosphate. In this instance, the monopotassium phosphate content is equivalent to 207 mg/L (47 mg/L divided by 0.227). The injector ratio and stock tank volume should be taken into account while calculating this quantity. Therefore, 4.14 grams of monopotassium phosphate would be needed for a 100-liter stock tank with a 200-injector ratio.

4. **Potassium (K)**
    - Potassium requirements are met through various sources. If additional K is needed, calculate and add accordingly.
    - No additional K needed in this example.
5. **Nitrogen (N)**
    - Nitrogen requirements are met through various sources. If additional N is needed, calculate and add accordingly.
    - Potassium nitrate (38.6% K, 13.7% N) can be used if more N is required.
    - Target: 90 ppm (current: 85 ppm from calcium nitrate)
    - Formula: Target ppm−Current ppm% N / %N in potassium nitrate
    - Calculation: 90 mg/L−85 mg/L/0.137=36.5 mg/L potassium nitrate
    - Adjust for stock tank volume and injector ratio.
    - Result: 36.5 mg/L×100 L×200 (injector ratio)/1000 mg/g=0.73 g potassium nitrate

Many sources can be utilized to supply the nitrogen (N) needed for hydroponic fertilizer solutions. If more nitrogen is required, it should be determined and provided suitably. If additional nitrogen is needed for this, potassium nitrate (38.6% K, 13.7% N) might be utilized. The present calcium nitrate level is 85 ppm, but the goal level is 90 ppm. The formula is the target ppm minus the present ppm divided by the proportion of nitrogen in potassium nitrate to determine the required quantity of potassium nitrate. In this instance, the potassium nitrate content is (90 mg/L - 85 mg/L) / 0.137 = 36.5 mg/L.

This calculated amount should be adjusted for the stock tank volume and injector ratio. So, for a 100-liter stock tank with a 200-injector ratio, the result would be 0.73 g of potassium nitrate required.

6. **Sulfur (S)**
    - Sulfur requirements are met through various sources. If additional S is needed, calculate and add accordingly.
    - Potassium sulphate (18.3% S) can be used if more S is required.
    - Target: 62 ppm (current: 54 ppm from magnesium sulphate)
    - Formula: Target ppm−Current ppm% S / % S in potassium sulphate
    - Calculation: 62 mg/L−54 mg/L/0.183=43.7 mg/L potassium sulphate
    - Adjust for stock tank volume and injector ratio.
    - Result:
      43.7 mg/L×100 L×200 (injector ratio)/1000 mg/g=0.874 g potassium sulphate

    Different sources can be used to meet the sulphur (S) needs in hydroponic fertilizer solutions. If more sulphur is required, it should be determined and supplied appropriately. For example, if sulphur is needed, potassium sulphate (18.3% S) might be used. The present amount of sulphur from magnesium sulphate is 54 ppm, whereas the goal level is 62 ppm. The formula is the target ppm minus the present ppm divided by the percentage of sulphur in potassium sulphate to determine the required quantity of potassium sulphate. It is (62 mg/L - 54 mg/L) / 0.183 = 43.7 mg/L of potassium sulphate in this instance. This calculated amount should be adjusted for the stock tank volume and injector ratio. So, for a 100-liter stock tank with a 200-injector ratio, the result would be 0.874 g of potassium sulphate required.

7. **Chloride (Cl)**
    - Chloride requirements are met through potassium chloride(47.6% Cl and 52.2% K).
    - Target: 89 ppm
    - Formula: Target ppm/%Cl in potassium chloride.
    - Calculation: 89 mg/L/0.476=187 mg/L potassium chloride
    - Adjust for stock tank volume and injector ratio.
    - Result:
      187 mg/L×100 L×200 (injector ratio)/1000 mg/g=3.74 g Potassium chloride

In hydroponic fertilizer solutions, potassium chloride (47.6% Cl and 52.2% K) can be utilized to meet the chloride (Cl) needs. 89 ppm is the desired amount of chloride. The target ppm divided by the percentage of Cl in potassium chloride yields the required quantity of potassium chloride, which is 89 mg/L / 0.476 = 187 mg/L. The injector ratio and stock tank volume should be taken into account while calculating this quantity. For instance, the needed amount of potassium chloride for a 100-liter stock tank with a 200-injectors ratio would be 3.74 g.

List of crops that can be grown in hydroponics

Table3.Crops that can ~~be producebe~~ be produced on commercial level using soil-less culture

Types of crops	Crops
CEREALS	*Oryza sativa* (Rice), *Zea mays* (Maize)
FRUITS	*Fragaria ananassa* (Strawberry)
VEGETABLES	*Lycopersicon esculentum* (Tomato), *Capsicum frutescens* (Chilli), *Solanum melongena* (Brinjal), *Phaseolus vulgaris* (Green bean), *Beta vulgaris* (Beet), *Psophocarpus tetragonolobus* (Winged bean), *Capsicum annum* (Bell pepper), *Brassica oleracea var. capitata* (Cabbage), *Brassica oleracea var. botrytis* (Cauliflower), *Cucumis sativus* (Cucumbers), *Cucumis melo* (Melons), *Raphanus sativus* (Radish), *Allium cepa* (Onion)
LEAFY VEGETABLES	*Lactuca sativa* (Lettuce), *Ipomoea aquatica* (Kang Kong)
CONDIMENTS	*Petroselinum crispum* (Parsley), *Mentha spicata* (Mint), *Ocimumbasilicum* (Sweet basil), *Origanum vulgare* (Oregano)
FLOWER/ ORNAMENTAL CROPS	*Tagetes patula* (Marigold), *Rosa berberifolia* (Roses), *Dianthuscaryophyllus* (Carnations), *Chrysanthemum indicum* (Chrysanthemum)
MEDICINAL CROPS	*Aloe vera* (Indian Aloe), *Solenostemonscutellarioides* (Coleus)
FOODER CROPS	

	Sorghum bicolor (Sorghum), *Medicago sativa* (Alphalfa), *Hordeumvulgare* (Barley), *Cynodondactylon* (Bermuda grass), *Axonopuscompressus* (Carpet grass)

Source:(Maharana and Koul, 2011)[17]

Nutrient formulations for different crop

Every crop cultivated requires a different set of nutrient solutions, which must be modified during the crop's growth cycle. Fruit crops, including tomatoes and cucumbers, require to maintain relatively low N levels, whereas root crops require greater K and leaf crops typically require higher N.

Table4. List of fertilizer salts along with their element supplied

Fertilizer Salts	**Element supplied**
Boric Acid [H_3BO_3]	B
Calcium nitrate [$Ca(NO_3)_2 \cdot 4H_2O$] (15.5-0-0)	N, Ca
Cupric chloride [$CuCl_2 \cdot 2H_2O$]	Cu
Copper sulphate [$Cu(SO_4) \cdot 5H_2O$]	Cu
Chelated iron (9%)	Fe
Ferrous sulphate [$FeSO_4$]	Fe
Magnesium sulphate [$MgSO_4 \cdot 7H_2O$] (Epsom salts)	Mg
Manganese chloride [$MnCl_2 \cdot 4H_2O$]	Mn
Manganese sulphate [$MnSO_4 \cdot 4H_2O$]	Mn
Molybdenum trioxide [MoO_3]	Mo
Monopotassium phosphate [KH_2PO_4] (0-22.5-28)	K, P
Potassium chloride [KCl] (0-0-49.8)	K
Potassium nitrate [KNO_3] (13.75-0-36.9)	K, N
Potassium sulphate [K_2SO_4] (0-0-43.3)	K
Zinc sulphate [$ZnSO_4 \cdot 7H_2O$]	Zn

Source: (Jensen and Malter, 1995) [18]

General nutrient formulation for hydroponic crops

For hydroponic crops to be grown successfully and obtain the necessary nutrients for strong growth and development, a well-balanced nutrient solution is required. This formulation will serve as a fundamental guideline for nutrient solutions specific to the vegetative, flowering, and fruiting stages of plant growth. Note that the amounts shown are for one US gallon(3.78 L) of solution.

~~Nutrients~~Nutrientformulations for vegetative stage

Table 5.~~Nutrients~~Nutrientformulation at the vegetative stage for hydroponic crops

Fertilizer salts	Amount (gms)
Calcium Nitrate	6.00
Magnesium Sulphate	2.42
Potassium Nitrate	2.09
Monopotassium Phosphate	1.39
Potassium Sulphate	0.46
7% Fe Chelated Trace Elements	0.40

Source: (HGS Hydro, 2023) [19]

Nutrients formulation for flowering stage

Table 6.Nutrientsformulation at flowering stage for hydroponic crops

Fertilizer salts	Amount (gms)
Calcium Nitrate	8.00
Magnesium Sulphate	2.80
Potassium Nitrate	2.40
Monopotassium Phosphate	0.46
Potassium Sulphate	1.39
7% Fe Chelated Trace Elements	0.40

Source:(HGS Hydro, 2023) [19]

Nutrients formulation for fruiting stage

Table 7. **Nutrientsformulation at fruiting stage for hydroponic crops**

Fertilizer salts	Amount (gms)
Calcium Nitrate	8.00
Magnesium Sulphate	2.40
Potassium Nitrate	2.80
Monopotassium Phosphate	1.39
Potassium Sulphate	1.70
7% Fe Chelated Trace Elements	0.40

Source:(HGS Hydro, 2023) [19]

Nutrient formulations for tomatoes, cucumbers and peppers under hydroponics

Compared to leafy greens, fruiting crops often have greater nutritional requirements. It's critical to raise the potassium, calcium, and magnesium levels in addition to the nitrogen. Tomatoes, cucumbers, and peppers have all grown effectively with a single fertilizer formula. Commercial operations for tomatoes frequently change the nutrient solution formula based on the crop's growth stage. To promote healthy plant structure and vegetative development, the initial approach is usually to provide higher levels of nitrogen, calcium, and magnesium. The tomato seedling is then moved, and after about six weeks, potassium is added and nitrogen is decreased to encourage the tomato seedling's shift from vegetative development to flowering and fruit set. Lastly, as the plant develops and bears fruit, the formula may need to be modified once more to balance vegetative and reproductive development.When growing tomatoes through hydroponics it can be determined that the nutrient solution, growth stimulants, and growth substrate are the main influencing components. Tomato plants grown using the soilless approach grew faster and yielded more overall than those grown in soil. Soilless agriculture yielded an average marketable output of 92.1% as opposed to 77.0% when compared to in-soil farming[20].

Table 8.Hydroponic nutrientsformulationfor preparing 3.78Liters of fertilizer suitable for hydroponic production of tomatoes, cucumbers and peppers

UA CEAC Formulation			
TANK A		**TANK B**	
Fertilizer Salt	**Amount(gms)**	**Fertilizer Salt**	**Amount(gms)**
$Ca(NO_3)_2 \cdot 4H_2O$	347.8 g	KH_2PO_4	64.9 g
KNO_3	152.5 g	$MgSO_4 \cdot 7H_2O$	184.3 g
10% Iron-DTPA Sprint 330 or Sequestrene 330	7.6 g	K_2SO_4	114.7 g
		$MnSO_4 \cdot 4H_2O$	0.641g
		H_3BO_3	0.606g
		$Na_2MoO_4 \cdot 2H_2O$	0.048g
		$ZnSO_4 \cdot 7H_2O$	0.549g
		$Cu(SO_4) \cdot 5H_2O$	0.074g

Source:(Mattson and Peters, 2017) [21]

**UA CEAC:University of ArizonaControlled Environment Agriculture Center*

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Nutrient formulations for lettuce, herbs and leafy greens under hydroponics

Lettuce is the most popular crop cultivated hydroponically; 99% of its leaves are viable and healthy, and it can be sold for around 40% more than lettuce grown in the conventional way[22].Hydroponic lettuce and herbs are among the leafy greens that offer an apparent benefit in terms of nutritional management. Throughout their entire production cycle, leafy greens largely concentrate on vegetative development, in contrast to fruiting crops, whose nutritional requirements change as the plant ages. This feature makes it practical for farmers to apply a static nutrition formulation, which simplifies the procedure and encouragesmaximum leaf output.Leafy greens need a steady supply of ~~the~~ vital nutrients for maximum leaf formation, and the static formula provides it by keeping the N-P-K ratio constant throughout the vegetative growth cycle. This minimizes the need for complex alterations throughout cultivation, making it a more efficient and dependable method.

Table9.This hydroponic nutrient solution formulation is made to prepare 3.78 Liters of fertilizer suitable for hydroponic production of lettuce, herbs and leafy greens

Modified Sonneveld's solution					
TANK A			**TANK B**	
Fertilizer Salt	**Amount(gms)**		**Fertilizer Salt**	**Amount(gms)**
$Ca(NO_3)_2·4H_2O$	184.0 g		KH_2PO_4	51.5 g
KNO_3	167.3 g		$MgSO_4·7H_2O$	93.1 g
10% Iron-DTPA Sprint 330 or Sequestrene 330	3.8 g		$MnSO_4·4H_2O$	0.290g
$NH_4 NO_3$	14.4 g		H_3BO_3	0.352g
			$Na_2 MoO_4 ·2H_2 O$	0.023g
			$ZnSO_4·7H_2O$	0.217g
			$Cu(SO_4)·5H_2O$	0.035g

Source:(Mattson and Peters, 2017) [21]

Conclusion

The analysis concludes by highlighting the vital function that nutrient solutions play in hydroponic systems for sustainable agricultural practices. Food security, water shortage, and environmental degradation are issues that farmers may solve by converting to modern farming methods like hydroponics. Hydroponic farming is a viable approach to addressing the growing need for food production since it has several advantages such as effective water utilization, higher crop yields, and precise control over growth conditions.To maximize plant development and guarantee resource efficiency, nutrient solutions must be managed, which includes keeping an eye on pH, electrical conductivity, and total dissolved solids. Through precise nutrient level adjustment based on crop requirements and development phases, farmers may minimize environmental consequences and maximize harvests.The analysis also emphasizes how crucial accurate fertilizer calculations are to maintain the ideal nutrient levels in hydroponic systems. Fertilizer compatibility, elemental values, conversion factors, and other guidelines can help farmers customize nutrient solutions to fulfil the unique requirements of various crops at different stages of growth.Broadly, hydroponic farming allows farmers to overcome the difficulties involved with traditional farming methods by providing a sustainable and effective approach to agriculture. Farmers have the opportunity to create a resilient agricultural model that promotes economic growth and environmental sustainability by embracing novel techniques and concentrating on nutrient management.

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