Nutrient & irrigation management practices for greenhouse vegetables production

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Advantages of hydroponic vegetables production

1. An alternative solution to address problems caused by **soil-borne diseases** (e.g., fusarium, verticillium, pythium, etc.). Initiating cultivation in an environment free from pathogens in the root zone.
2. Elimination of **weeds** from the crop.
3. Resolving the problem of **low soil fertility** in many cases, either due to their intensive exploitation and monoculture or unfavorable natural properties (e.g., saline soils, heavy soils, soils with low organic matter content).
4. Practical evidence shows that cultivating on high-quality substrates and using a clean nutrient solution significantly promotes **earliness** of the harvest. This is attributed to the ability to maintain higher temperatures in the root zone.
5. Soilless cultivation frees the grower from **soil preparation** tasks (plowing, tilling, basic fertilization, etc.), reducing labor needs, and allowing for immediate planting of a new crop after removing the previous one.
6. It results in **increased yields** due to higher planting density, optimal nutrition, the ability to maintain higher temperatures in the root zone during cold periods, and the superior physicochemical properties of substrates compared to soil.
7. Automation and **mechanization** of cultivation operations.

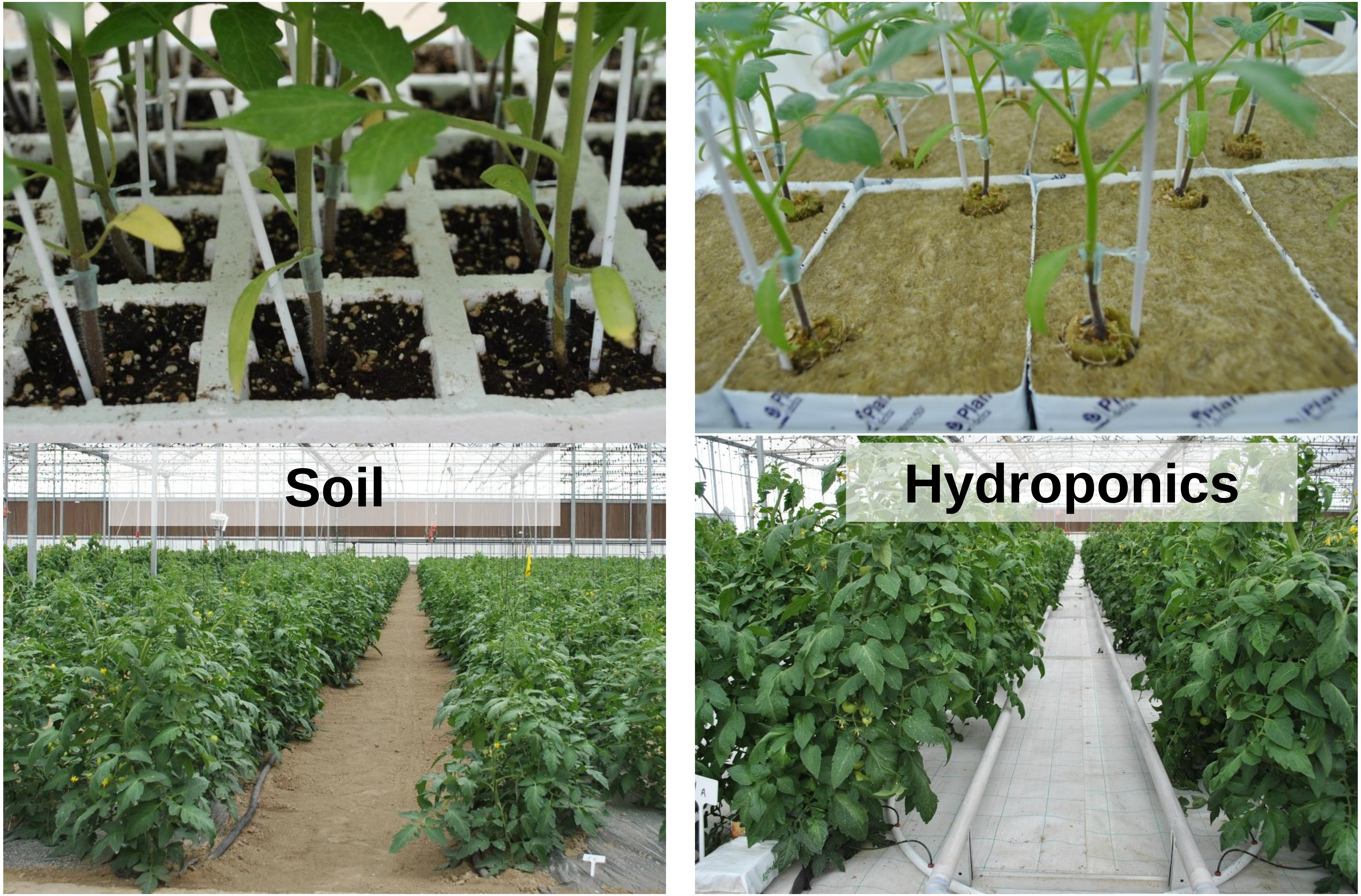






Soil

Hydroponics


Soil
Hydroponics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Disadvantages of hydroponic vegetables production

1. The **cost** of the initial installation of a hydroponic unit is higher compared to the corresponding cost for soil-based cultivation.
2. **Complexity** in the handling of water and nutrient solutions.
3. In closed irrigation systems, there is a risk of spreading contamination if a plant is affected, through the recycled nutrient solution. In practice, this risk is relatively small.
4. The manifestation of adverse effects from **mishandling** is faster and often more intense in hydroponic cultivation.
5. In open systems, there is a **risk of soil contamination** and possibly contamination of the water tables in the area where drainage is disposed.

General concepts and definitions

Hydroponics

Hydroponics is called every method of cultivating plants, whose root system develops outside natural soil. The roots grow either in a nutrient solution directly or on substrates to which the nutrient solution is added. It is often referred to as soilless culture.

Nutrient solution

It is a dilute aqueous solution containing all the essential nutrients for plants. The nutrients are typically dissolved in water as ions of inorganic salts. The nutrient solution can be directly delivered to the plant roots. Plants absorb water and nutrients from this solution.

Concentrated solutions

These are high-density nutrient solutions (usually 100 times more concentrated than feeding nutrient solutions), containing the essential inorganic nutrients in the correct proportion necessary for plant nutrition. Concentrated solutions are manufactured and stored in containers, from which small quantities are taken. These quantities are then diluted according to the irrigation water to create the feeding nutrient solutions for plants.

General concepts and definitions

Concentration of Hydrogen Ions (pH)

pH is the measure of the concentration of hydrogen ions (H+) in a solution, and its value crucially affects the solubility and consequently the availability of most nutrients in cultivation. For this reason, it is essential for the pH of nutrient solutions to be around 5.5.

(EC; Electrical Conductivity)

Electrical conductivity is a measure of the total concentration of salts in a solution and is used to estimate the adequacy of nutrient elements in it. Thus, the higher the concentration of salts, the greater the conductivity. The electrical conductivity of nutrient solutions used in most hydroponic cultivations for feeding should typically range between 1.5-2.5 dS/m.

The pH and EC are widely used for the daily monitoring of the suitability of the nutrient solution, thanks to their ease of measurement and quick assessment.

General concepts and definitions

Hydroponic Substrate

It is any natural or industrially processed porous material, excluding natural soil, capable of retaining a nutrient solution and air. Therefore, it can substitute for soil as a medium for root system development. Most substrates behave chemically as inert materials, meaning they do not contribute nutrients to the nutrient solution, nor do they bind ions present in it.

Rockwool substrate

Mineral rockwool is typically **used for 1-3 years**, after which it should be recycled or disposed of by burying it in the soil and covering it with a thick layer of soil.

It has a density of **70-80 kg/m^3**, with high moisture content in a saturated state (**90%**). Additionally, the water contained in the substrate is almost entirely available for the plants.

Mineral rockwool is characterized by a **very good water-to-air ratio**, the absence of pathogens, ease of use, structural stability, and is chemically inert substrate.

The main disadvantage is its **high purchasing cost** and the fact that it is **not biodegradable** in the soil.

Rockwool substrate

Cultivation in mineral **rockwool** slabs is internationally the most widespread method of growing plants in substrates.

The **pH** is approximately **7**, and it exhibits low electrical conductivity (EC).

The cultivation is done on slabs with a length of 0.8 – 1.2 m, with various widths and thicknesses. Typically, for vegetables, slabs with **dimensions** of **100 × 15 × 7.5 cm** are commonly used.

The **height** of the slabs should not exceed **8-10 cm** because the moisture content decreases abruptly.

Substrates

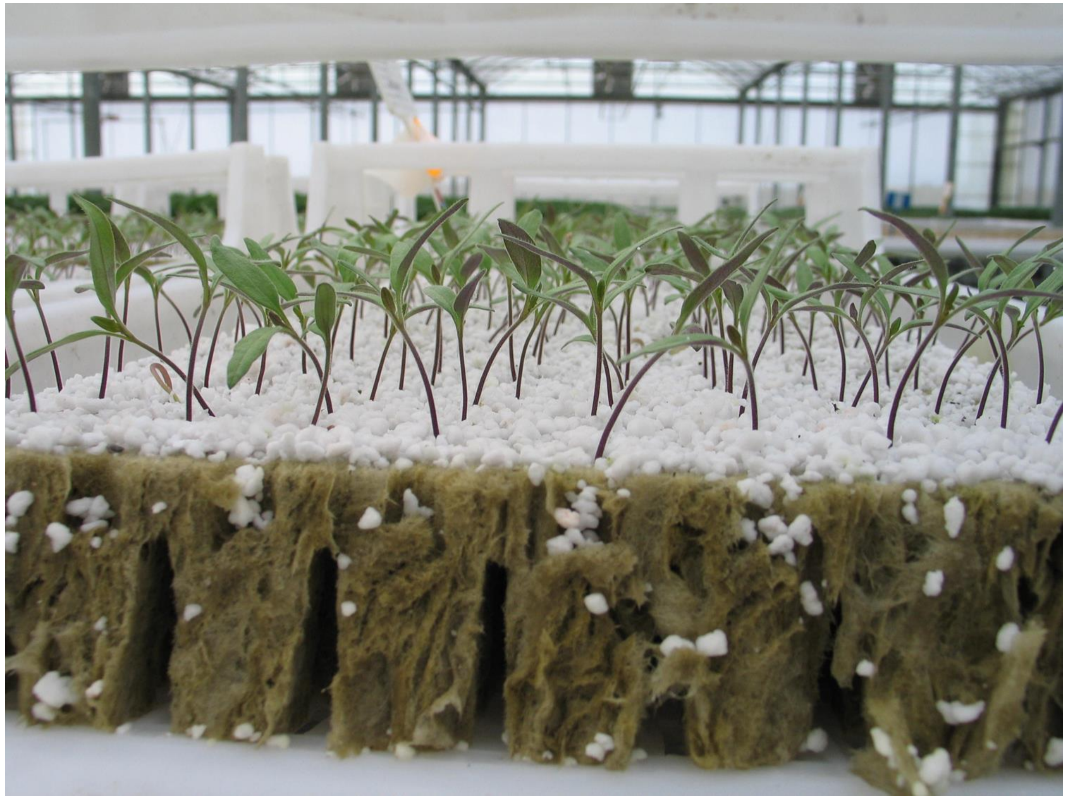
Before installing the plantation, the greenhouse ground should be leveled to ensure a uniform water supply throughout the area. It should be covered with plastic, black on the bottom, and white on the top surface. The slope along the length should not exceed 1-1.5%.

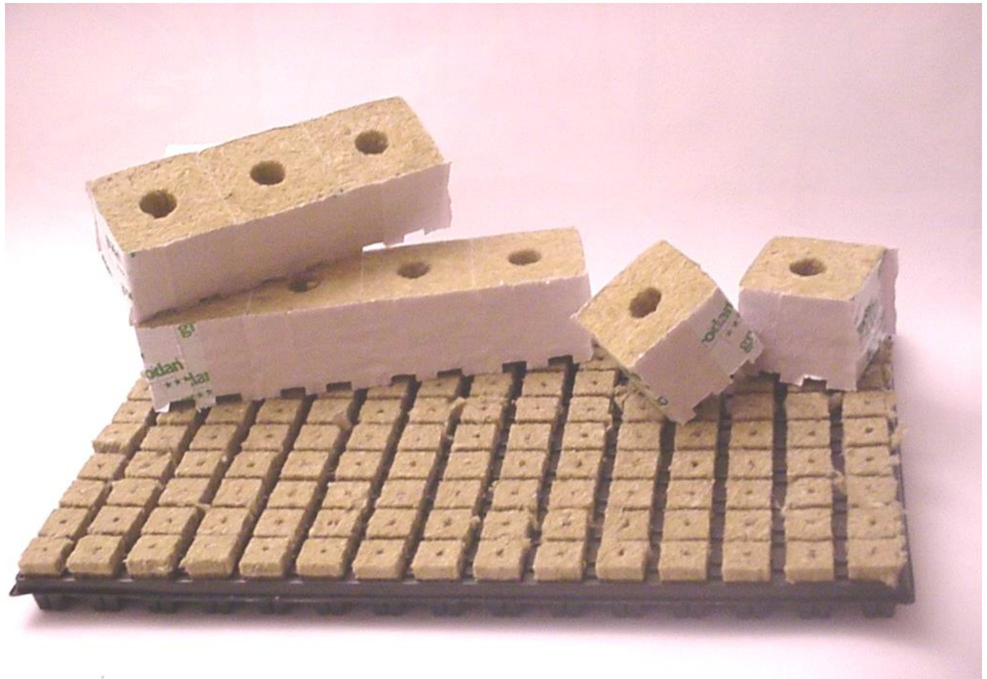
Substrates

Substrates

Irrigation lines are placed **parallel** to the rows of the slabs, in a horizontal plane and positioned **lower than the bags** to prevent the feeding tube from emptying after irrigation. The supply of nutrient solution to the plants is done by placing a flexible small-diameter plastic tube (**spaghetti type**) on the irrigation pipe, along with low-flow drip emitters.

Initially, the bags are irrigated with an acidic nutrient solution until saturation and are left filled for at least 24 hours before planting. During planting, a rockwool cube or a perforated small container with a suitable mix containing the seedling is placed in each position that has been opened.

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Substrates

After planting, **slits** are made on the sides of the bag (2-4 cm), in the middle of the distance between the irrigation positions (either vertically or at a 45° angle), for the drainage of excess nutrient solution. The slits may extend to the bottom of the bag or stop 1-3 cm higher.

Equipment of a hydroponic greenhouse

The main parts of the equipment that typically make up a standard hydroponic unit are as follows:

1. Nutrient solution preparation facilities
2. Fertilizer injection system
3. Nutrient solution transport and application system
4. Nutrient solution collection network



1. Nutrient solution preparation facilities

- The installations consist of water tanks and transport system.

1. Nutrient solution preparation facilities

- The installations consist of water tanks and transport system, and then containers where the concentrated solutions are prepared. Common practice dictates the use of **at least three containers** (barrels), which must be made of suitable material to prevent corrosion, oxidation, and the entry of sunlight, especially in the container where ferrous chloride is placed.

1. Nutrient solution preparation facilities

- In the first two containers (**container A and B), water-soluble fertilizers** are added in much larger quantities than needed for plant nutrition (hundreds of times more). The third container (**container C) contains the acid** necessary **to regulate the pH**. Their capacity is chosen based on the area of hydroponic cultivation, and it is recommended to have a mixing system.

- In recent years, large greenhouse units with powerful hydro-lubrication heads use a **separate container for each fertilizer**. The water used, regardless of its source (e.g., drilling, irrigation network), must be of good quality concerning salt content.
- The use of an appropriate **filtering system** is advisable to avoid problems of blockage in the supply system.

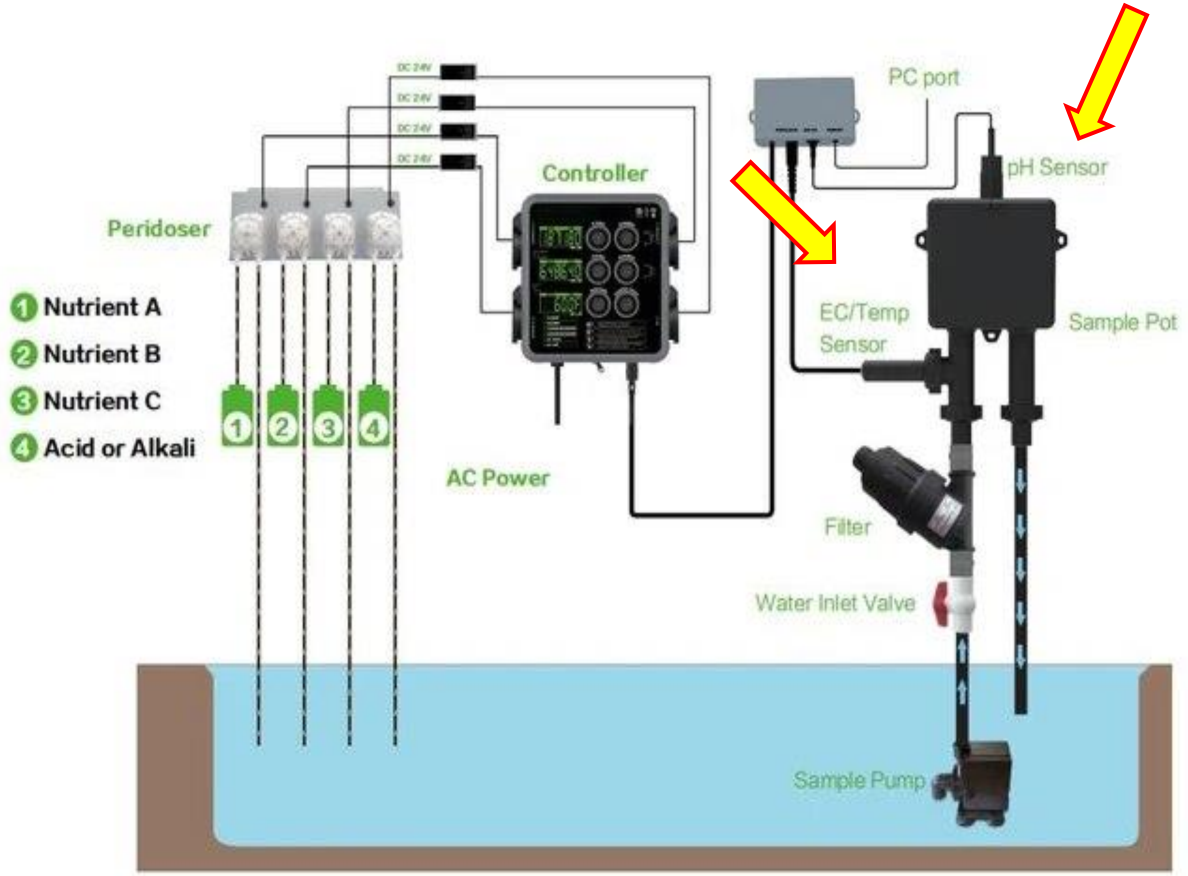
2. Fertilizer injection system

- The **automatic dilution unit (fertilizer injection system)** is primarily used for diluting concentrated solutions in a common container to prepare a **diluted nutrient solution for plant feeding.** The pumping of concentrated solutions is usually achieved by installing a **dosing pump** or **Venturi injectors** in each container. The concentrated solutions from Containers A and B, as well as the acid (Container C), are diluted by mixing them with irrigation water in the **mixing bucket** of the hydroponic head.

2. Fertilizer injection system

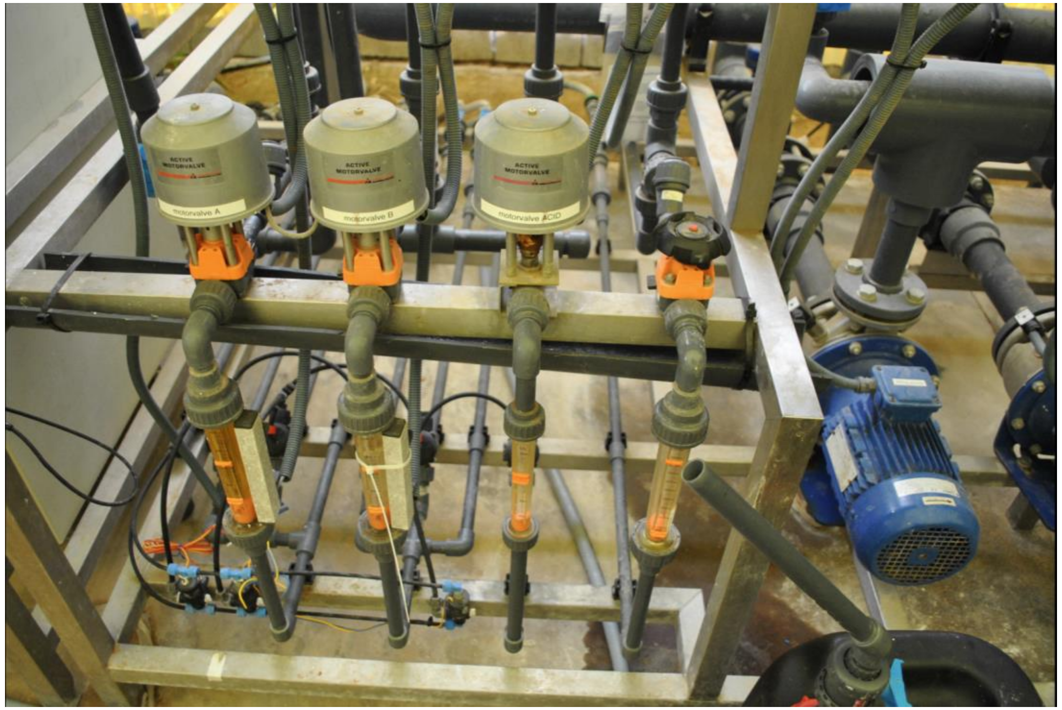
- To achieve the correct ratio of water dilution and concentrated fertilizers and the desired values of electrical conductivity (EC) and pH in the nutrient solution, the **installation of EC and pH measurement sensors** in the mixing container is necessary.

With the advancement of technology, **measurements are automated**, and real-time data is sent to the irrigation programmer. The programmer, usually connected to a computer screen, receives target values for EC, pH, and indirectly the desired concentrations and ratios of nutrient elements.



3. Nutrient solution transport and application system

- For the **circulation of the nutrient solution** in cultivations where substrates like rockwool or coconut are used, **a pipeline network is** employed on which the **irrigation system is installed (e.g., drippers)**. The transport pipelines, as in any irrigation network, are **the largest diameter pipes** used to convey water from the available water source (well, tank) to the hydroponic head. They typically consist of high-density **polyethylene (PE)** or **polyvinyl chloride (PVC)** pipes.



3. Nutrient solution transport and application system

- The **secondary pipelines**, serving to supply nutrient solution to the irrigation lines, have a **smaller diameter** than the main pipelines and are made of high-density PE to withstand high pressures. Finally, the irrigation lines are the smallest diameter pipes and are usually made of **flexible PE**. The irrigation system (e.g., drippers, microtube-type emitters) is placed on them, and low-flow **drippers** with **rates of 2-4 liters per hour** are used in the application system. Usually, **one dripper is used for each plant**.

4. Nutrient solution collection network

- A vital requirement for the smooth operation of a hydroponic unit is the installation of a nutrient solution collection system, achieved by constructing a network of channels and conduits. For this purpose, there should be a **slope** along the planting lines ranging from **0.5% to 1.5%**, allowing the proper flow of the **draining nutrient solution** towards the channels' outlets.
- The channels used for collecting the nutrient solution are often utilized as receptacles for the substrate as well.


4. Nutrient solution collection network

- The solution from the **drainage** collection channels is **collected in a tank**, which must have sufficient capacity so as not to overflow when all the excess nutrient solution is gathered, and it should be made of durable material that is non-toxic to plants.

- Its reuse in hydroponic cultivation, despite the management difficulties it presents, may possibly be its only alternative use in the future. At present, **its disposal in neighboring cultivation**, such as in vegetable farms, is the **common practice**, reducing the cost of fertilizer use in the field.

Nutrient solutions- **1. Composition**

In hydroponics, **complete nutrient solutions** are used, which are aqueous solutions containing **all the essential inorganic nutrients** for plant growth, except for carbon, which is taken from the atmosphere as CO_2.

Hydrogen and **oxygen** are components of **water**, and oxygen is also taken from the atmospheric **air** for respiration needs.

Some elements, during the preparation of a nutrient solution, are added in larger quantities **(N, P, S, K, Ca, and Mg)** and are called **macronutrients**, while the rest are added in much smaller quantities (**Fe, Mn, Zn, Cu, B, Mo, and Cl)** and are called **micronutrients**.

Therefore, only **12 out of the 16 essential chemical elements for plant growth need to be added** to the water when preparing a nutrient solution.

Macronutrient	Chemical form	Micronutrient	Chemical form
Nitrogen(N)	NO_3^-, NH_4^+	Iron (Fe)	Fe^{2+}
Phosphorus (P)	$H_2PO_4^-$	Manganese	Mn^{2+}
Sulfur (S)	SO_4^{2-}	Zinc (Mn)	Zn^{2+}
Potassium (K)	K^+	Copper (Cu)	Cu^{2+}
Calcium (Ca)	Ca^{2+}	Boron (B)	H_3BO_3
Magnesium (Mg)	Mg^{2+}	Molybdenum (Mo)	MoO_4^{2-}

Nutrient solutions- **2. Fertilizers for use**

For the preparation of nutrient solutions, simple **water-soluble fertilizers** are used, along with certain acids, while specifically **iron** is added in the form of **chelated** compounds **to avoid sedimentation**.

Fertilizer	Chemical form	Nutrients (%)	Molecular weight
Ammonium nitrate	NH_4NO_3	N: 35	80
Calcium nitrate	$5[Ca(NO_3)_2 \cdot 2H_2O]NH_4NO_3$	N: 15.5 Ca: 19	1080.5
Potassium nitrate	KNO_3	N: 13, K: 38	101.1
Magnesium nitrate	$Mg(NO_3)_2 \cdot 6H_2O$	N: 11, Mg: 9	256.3
Nitric acid	HNO_3	N: 22	63
mono-Ammonium phosphate	$NH_4H_2PO_4$	N: 12, P: 27	115
Potassium phosphate	KH_2PO_4	P: 23, K:28	136.1
Phosphoric acid	H_3PO_4	P: 32	98
Potassium sulphate	K_2SO_4	K: 45, S: 18	174.3
Mgnesium sulphate	$MgSO_4 \cdot 7H_2O$	Mg: 9.7, S: 13	246.3
Iron chelate	several types	Fe: 6-13	-
Manganese sulfate	$MnSO_4 \cdot H_2O$	Mn: 32	169
Zinc sulfate	$ZnSO_4 \cdot 7H_2O$	Zn: 23	287.5
Copper sulfate	$CuSO_4 \cdot 5H_2O$	Cu: 25	249.7
Sodium borate	$Na_2B_4O_7 \cdot 10H_2O$	B: 11	381.2
Boric acid	H_3BO_3	B: 17.5	61.8
Disodium octaborate	$Na_2B_8O_{13} \cdot 4H_2O$	B: 20.5	412.4
Ammonium molybdate tetrahydrate	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	Mo: 54	1163.3
Sodium molybdate dihydrate	$Na_2MoO_4 \cdot 2H_2O$	Mo: 40	241.9

Nutrient solutions- **3. Properties of the solutions**

In nutrient solutions, besides the **concentration** of each inorganic element and their **ratios**, **pH** and **electrical Conductivity (EC) are also of interest**. These two parameters can be easily and quickly determined with simple portable instruments (conductivity meter, pH meter) and are widely used for the daily monitoring of the suitability and quality of nutrient solutions.

Electrical Conductivity (EC) does not provide information about the specific **salts** dissolved in a solution but rather indicates their **total concentration**. The internationally established unit for measuring EC is dS/m. For most cultivated plants, the EC of nutrient solutions ranges between **1.5-2.5 dS/m**.

Nutrient solutions- **3. Properties of the solutions**

pH (acidity) of the nutrient solution measures its hydrogen ion concentration and is crucial for its suitability. For most plant species, pH **should be around 5.5-5.8** in the feeding solution and 5.5-6.3 in the root zone.

- → Many nutrients become less soluble (e.g., P, Fe, Mn) at alkaline pH (pH > 7), making their **absorption** by plants more challenging. On the other hand, at very acidic pH (pH < 5), they become more soluble, posing a risk of **phytotoxicity** (e.g., Mn, Al).
- → The **pH of irrigation water is usually alkaline** due to the presence of calcium (**Ca**) and magnesium (**Mg**) carbonate salts, and to reduce it to the desired levels in nutrient solutions, the addition of an acid is required.
- → The availability of trace elements in the nutrient solution is much more influenced by pH changes compared to macronutrients.

Nutrient solutions- **4. Preparation**

It is essential to use **at least two containers for concentrated solutions**, where, in the first container A, calcium nitrate, ammonium nitrate, a portion of potassium nitrate, and ferric iron are added. In the second container B, potassium sulfate, magnesium sulfate, monoammonium phosphate, monopotassium phosphate, phosphoric acid, and the remaining trace elements except for iron are added. Magnesium nitrate (if used) can be added to either of the two containers of concentrated solutions.

The main goal is to **avoid mixing calcium with phosphorus and sulfur**, creating insoluble compounds.

Usually, a **third container is used for nitric acid** to control the pH of the nutrient solution, keeping it between 5.5 and 6.0.

Nutrient solutions- **4. Preparation**

Other ions present in water that must be taken into account during nutrient solution preparation are sodium (**Na^+**) and **bicarbonates (HCO_3^-)**.

Therefore, from the fertilizer quantities recommended to be added, the amounts of nutrient elements contained in the used water **should be subtracted**. Therefore, to prepare a nutrient solution with a given composition, it is essential to know the **chemical composition of the irrigation water**.

Usually, the quantities of various nutrient units (ions) used in nutrient solutions are expressed in millimoles per liter (**mmol/L**) or milliequivalents per liter (meq/L) to facilitate calculations of relationships and balances. Trace element concentrations are usually given in micromoles per liter (**μmol/L**) or milligrams per liter (mg/L or ppm).

Nutrient solutions- **4. Preparation**

The compositions of **nutrient solutions** proposed by various researchers should be used as indicative of the recommended mutual ratios of nutrients for each plant. Before use, they **should be customized** for each cultivation, depending on the composition of the water used.

When **water** used for preparing nutrient solutions comes from wells, dams, or natural sources, it is certain that it contains **significant amounts of inorganic ions**. From macroelements, water contains calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfates (SO_4^{2-}), and occasionally nitrogen (NO_3^-), while from trace elements, besides chlorine (Cl^-), there may be iron (Fe; not considered in calculations, precipitates with phosphates), manganese (Mn2+), zinc (Zn2+), copper (Cu2+), and boron (B).

Nutrient solutions- **4. Preparation**

The **ionic balance of the solution** dictates that the composition of a nutrient solution should be balanced in terms of the concentrations of **anions and cations** of the main nutrient elements (including hydrogen ions when the addition of acid is considered for pH regulation), expressed in meq/l. Therefore, the equality should hold:

$$\Sigma(\text{meq/l cations}) = \Sigma(\text{meq/l anions}) = C\ (\text{meq/l})$$

$$[NH_4^+] + [K^+] + [Ca_2^+] + [Mg_2^+] + [H_3O^+] = [NO_3^-] + [H_2PO_4^-] + [SO_4^{2-}] = C$$

The total ion concentration (C) in meq/l in the nutrient solution is empirically calculated to be approximately $C \approx EC \times 10$, as already mentioned. Therefore, electrical conductivity (EC) can be approximately determined by the relationship: $EC = C/10$, in dS/m.

In summary, it is noted that when formulating the basic composition of a nutrient solution, the following should be taken into account:

- ✓ **The type of cultivated plant, the growth stage, and** the **weather conditions**.
- ✓ The total salt concentration (**EC**), which must have a specified value, and the **pH** should be within **certain limits**.
- ✓ The levels or **mutual ratios** of nutrient elements.

Nutrient solutions- **5. Composition**

Recommended concentration of minerals in the nutrient solution of **hydroponically grown tomato** (open system) during several growing stages

		Drenching	Cluster 1-3	Cluster 3-5	Cluster 5-10	Cluster 10-
EC	dS/m	2.80	2.50	2.40	2.40	2.20
pH opt		5.60	5.60	5.60	5.60	5.60
[K]	mmol/l	7.25	7.75	7.00	7.50	6.50
[Ca]	mmol/l	6.50	4.25	5.00	4.75	4.25
[Mg]	mmol/l	2.50	2.75	2.00	2.00	2.00
[NH_4]	mmol/l	0.75	1.25	1.00	1.00	1.00
[NO_3]	mmol/l	15.50	15.00	12.00	12.00	10.70
[SO_4]	mmol/l	4.50	3.00	4.10	4.10	3.75
[H_2PO_4]	mmol/l	1.00	1.50	1.30	1.30	1.30
[Fe]	μmol/l	15	15	15	15	15
[Mn]	μmol/l	10	10	10	10	10
[Zn]	μmol/l	4	4	4	4	4
[Cu]	μmol/l	0.7	0.7	0.7	0.7	0.7
[B]	μmol/l	40	30	30	30	30
[Mo]	μmol/l	0.5	0.5	0.5	0.5	0.5

Recommended concentration of minerals in the nutrient solution of hydroponically grown **vegetables**, if no specific is available

Macronutrients (mmol/l)							
SPECIES	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}
Pepper	11-12	1-1,25	2-4	0.5	5-6	3-4	1-2
Melon	9-16	1-1,25	2-4	0.5	5-8	3-4	1-2
Watermelon	11-12	1-1,25	2-4	0.5	7	4-5	1-2
Cuccumber	12-13	1-1,25	2-4	0.5	5.5-6	3.5-4	1-2
Beans	10-14	1-1,25	2-3	0.5	6.5-8	3-5	1-2
Zucchini	10-12,5	1,5-1,8	2.5	0.5	7-8	3-4	1.5-2.5
Tomato	10-18	1-1,5	3-5	0.5	7-9	4-6	1.5-2.5

Micronutrients (μmol/l)						
ΦΥΤΟ	Fe	Mn	Zn	B	Cu	Mo
Pepper	10	10	4	25	0.5	0.5
Melon	30	15	4	25	0.5	0.5
Watermelon	10	10	4	20	0.5	0.5
Cuccumber	10	10	4	20	0.5	0.5
Beans	16-30	14-16	2-3	14-16	1-1.5	0.5-1
Zucchini	16-30	14-16	2-3	14-16	1-1.5	0.5-1
Tomato	16-30	12-18	2-3	12-20	1-2	0.5-1.5

Nutrient solutions- **6. Calculation of the fertilizer rates**

	mmol/l
NO_3^-	11.75
$H_2PO_4^-$	1.25
SO_4^{2-}	1
NH_4^+	0.5
K^+	5.5
Ca^{2+}	3.5
Mg^{2+}	1

	µmol/l
Fe	35
Mn	20
Zn	4
B	20
Cu	0.5
Mo	0.5

Fertilizer	mmol/l	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	**Ca^{2+}**	Mg^{2+}	Fe	Mn	Zn	B	Cu	Mo
$Ca(NO_3)_2$	3.5	7					3.5							
$MgSO_4$														
NH_4NO_3														
KH_2PO_4														
KNO_3														
DTPA														
MnSO4·H2O														
ZnSO4·7H2O														
Na2B4O7 10H2O														
CuSO4·5H2O														
Na2MoO4·2H2O														

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K^+	5.5
Ca^{2+}	3.5
Mg^{2+}	1

	µmol/l
Fe	35
Mn	20
Zn	4
B	20
Cu	0.5
Mo	0.5

Fertilizer	mmol/l	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	B	Cu	Mo
$Ca(NO_3)_2$	3.5	7					3.5							
$MgSO_4$	1			1				1						
NH_4NO_3														
KH_2PO_4														
KNO_3														
DTPA														
MnSO4·H2O														
ZnSO4·7H2O														
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K^+	5.5
Ca^{2+}	3.5
Mg^{2+}	1

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Mn	20
Zn	4
B	20
Cu	0.5
Mo	0.5

Fertilizer	mmol/l	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	B	Cu	Mo
$Ca(NO_3)_2$	3.5	7					3.5							
$MgSO_4$	1			1				1						
NH_4NO_3	0.5	0.5			0.5									
KH_2PO_4														
KNO_3														
DTPA														
MnSO4·H2O														
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Ca^{2+}	3.5
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	µmol/l
Fe	35
Mn	20
Zn	4
B	20
Cu	0.5
Mo	0.5

Fertilizer	mmol/l	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	B	Cu	Mo
$Ca(NO_3)_2$	3.5	7					3.5							
$MgSO_4$	1			1				1						
NH_4NO_3	0.5	0.5			0.5									
KH_2PO_4	1.25		1.25			1.25								
KNO_3														
DTPA														
MnSO4·H2O														
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SO_4^{2-}	1
NH_4^+	0.5
K^+	5.5
Ca^{2+}	3.5
Mg^{2+}	1

	µmol/l
Fe	35
Mn	20
Zn	4
B	20
Cu	0.5
Mo	0.5

Fertilizer	mmol/l	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	B	Cu	Mo
$Ca(NO_3)_2$	3.5	7					3.5							
$MgSO_4$	1			1				1						
NH_4NO_3	0.5	0.5			0.5									
KH_2PO_4	1.25		1.25			1.25								
KNO_3	4.25	4.25				4.25								
DTPA														
MnSO4·H2O														
ZnSO4·7H2O														
Na2B4O7 10H2O														
CuSO4·5H2O														
Na2MoO4·2H2O														

Nutrient solutions- **6. Calculation of the fertilizer rates**

	mmol/l
NO_3^-	11.75
$H_2PO_4^-$	1.25
SO_4^{2-}	1
NH_4^+	0.5
K^+	5.5
Ca^{2+}	3.5
Mg^{2+}	1

	µmol/l
Fe	35
Mn	20
Zn	4
B	20
Cu	0.5
Mo	0.5

Fertilizer	mmol/l	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	B	Cu	Mo
$Ca(NO_3)_2$	3.5	7					3.5							
$MgSO_4$	1			1				1						
NH_4NO_3	0.5	0.5			0.5									
KH_2PO_4	1.25		1.25			1.25								
KNO_3	4.25	4.25				4.25								
SUM		**11.75**	**1.25**	**1**	**0.5**	**5.5**	**3.5**	**1**						
DTPA														
MnSO4·H2O														
ZnSO4·7H2O														
Na2B4O7 10H2O														
CuSO4·5H2O														
Na2MoO4·2H2O														

Nutrient solutions- **6. Calculation of the fertilizer rates**

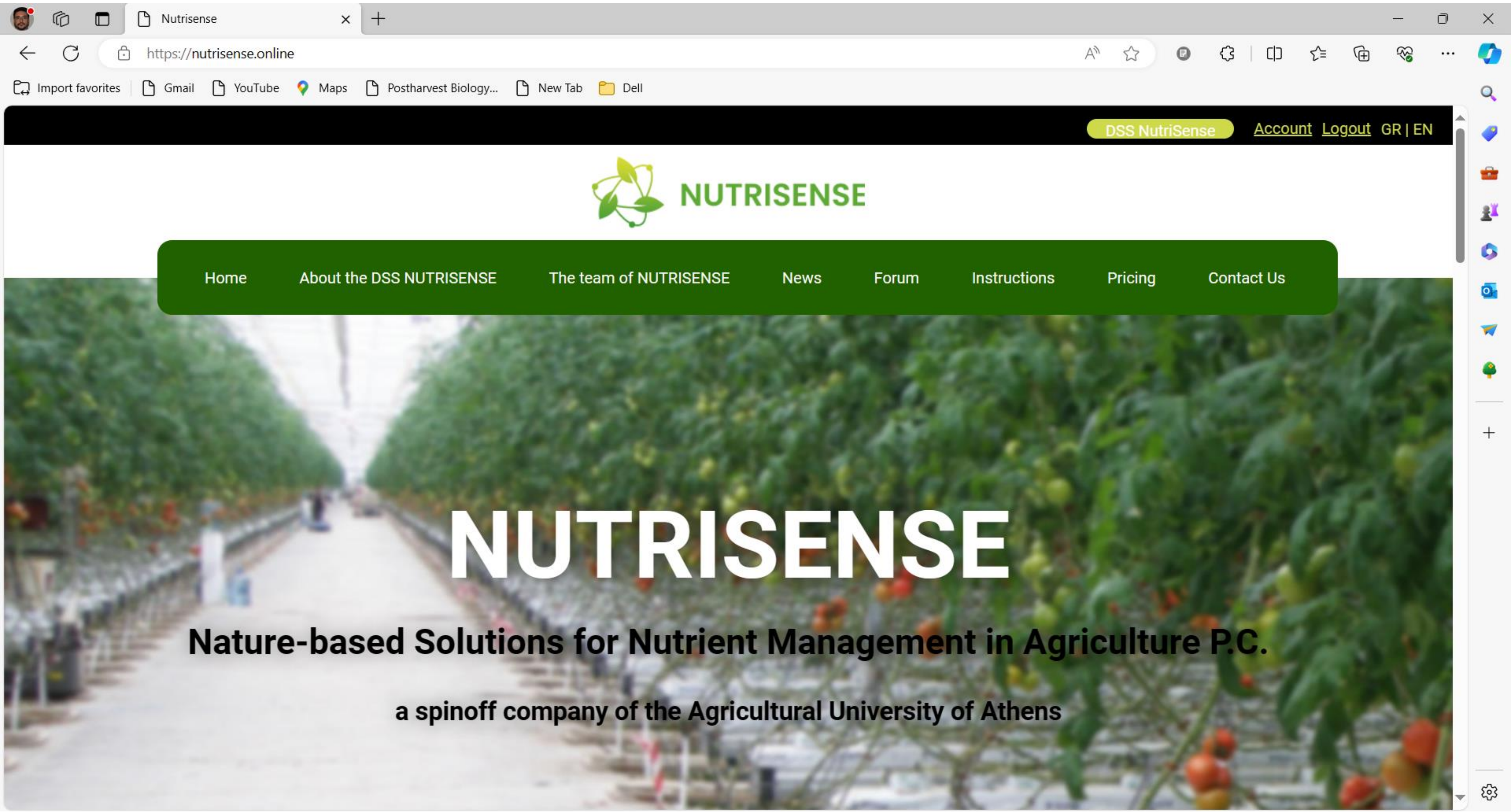
	mmol/l
NO_3^-	11.75
$H_2PO_4^-$	1.25
SO_4^{2-}	1
NH_4^+	0.5
K^+	5.5
Ca^{2+}	3.5
Mg^{2+}	1

	µmol/l
Fe	35
Mn	20
Zn	4
B	20
Cu	0.5
Mo	0.5

Fertilizer	mmol/l	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	B	Cu	Mo
$Ca(NO_3)_2$	3.5	7					3.5							
$MgSO_4$	1			1				1						
NH_4NO_3	0.5	0.5			0.5									
KH_2PO_4	1.25		1.25			1.25								
KNO_3	4.25	4.25				4.25								
	µmol/l													
DTPA	35								35					
MnSO4·H2O	20									20				
ZnSO4·7H2O	4										4			
Na2B4O7 10H2O	4											20		
CuSO4·5H2O	0.5												1	
Na2MoO4·2H2O	0.5													1

Nutrient solutions- **6. Calculation of the fertilizer rates**

Fertilizer	mmol/l	g/mol	NS on drip (mg/l)	NS concentrated (kg/m^3)
$Ca(NO_3)_2$	3.5	181	634	**63.4**
$MgSO_4$	1	246.3	246	**24.6**
NH_4NO_3	0.5	80	40	**4**
KH_2PO_4	1.25	136.1	170	**17**
KNO_3	4.25	101.1	430	**43**
	µmol/l	g/mol	NS on drip (µg/l)	NS concentrated (g/m^3)
DTPA (9% Fe)	35	621	21.74	2174
MnSO4·H2O (32%Mn)	20	169	3.38	338
ZnSO4·7H2O (23%Zn)	4	287.5	1.15	115
Na2B4O7 10H2O (11%B)	4	381.2	1.52	152
CuSO4·5H2O (25%Cu)	0.5	249.7	0.12	12
Na2MoO4·2H2O (40%Mo)	0.5	241.9	0.12	12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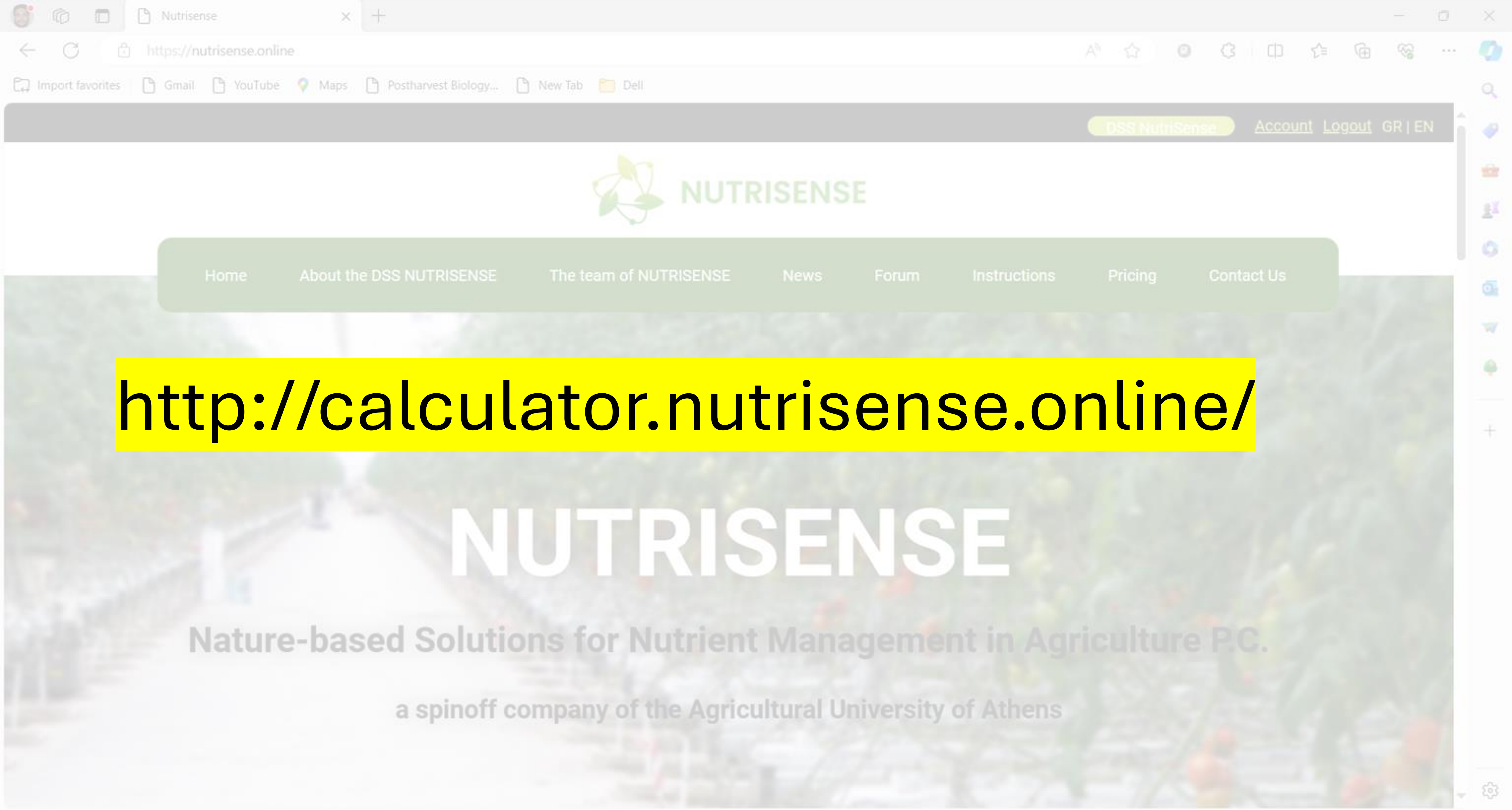


http://calculator.nutrisense.online/

Irrigation – Fertigation

- When we refer to **irrigation** in hydroponic cultivation, we mean the **supply of the nutrient solution** to the plant.
- The **quantity of water** that needs to be administered in **soilless** cultivation usually does not differ significantly compared to the amounts provided in **similar greenhouse cultivation in soil**, given that the other factors are similar.
- *Often, water consumption in hydroponic cultivation is even lower because there are no losses due to evaporation from the soil.*
- In **each irrigation** cycle, the water consumed between two successive waterings must be replaced so that the substrate reaches its **water-holding capacity** (maximum amount of water it can retain).
- The **duration of irrigation** (irrigation dose) does not depend on the plants but mainly **on the properties of the substrate**, while
- the **frequency of irrigation** depends **on the plant and climatic conditions** (e.g., sunlight, temperature).
- Soilless cultivations are **irrigated multiple times during the day**, with a certain frequency based on the rate of water absorption by the plants.

Irrigation – Fertigation

1. **Watering at predetermined times:** Producers typically apply sufficient water according to a fixed watering schedule to ensure an adequate water supply for the cultivation based on their experience.

2. **Electrical conductivity in the substrate:** Measurements of electrical conductivity (EC) in the substrate are regularly taken at specified intervals. It should be maintained at most one to one and a half times higher than the EC of the nutrient solution supply.

3. **Irrigation based on substrate moisture:** Estimation of the water status in the substrate can be achieved through continuous monitoring and recording of changes in the substrate's weight.

4. **Method for measuring drainage nutrient solution:** In each irrigation, approximately 20-30% of the applied nutrient solution should drain to ensure adequate irrigation and maintain the desired ratio of nutrients in the root environment.

Irrigation – Fertigation

5. **Irrigation based on solar energy:** When the cumulative solar energy reaches a certain reference value [140-180 J/cm^2 (1 Wh/m^2 = 0,36 J/cm^2)], irrigation is activated and starts accumulating again for the next irrigation.

6. **Irrigation based on transpiration:** Given that 99% of the water absorbed by plants is lost through transpiration, the volume of water absorbed by the plants becomes equal to the irrigation dose minus the fraction of transpiration.

7. **Irrigation based on physiological parameters:** By correlating the water status of plants with some or a combination of indicators of the plant's physiological condition (e.g., shoot diameter, sap flow, stomatal conductance, leaf reflectance, etc.).

Irrigation – Fertigation

Generally, for irrigating plants in substrates, the low-flow rate **drip system** is used, providing **2-4 liters per hour**.

The **frequency** of irrigation applied to porous substrates is primarily based on **human factors, sensors**, and irrigation models. Key sensors include **moisture** sensors, **electrical conductivity** sensors, weight changes in plants and substrates, leaf sap flow variations, or determination of draining water. Irrigation based on a model in greenhouse scenarios primarily relies on solar radiation and plant parameters.
However, the **irrigation rate** is determined by the **water-holding capacity of the substrate** and the **quality of the irrigation water.**

Regardless of the chosen irrigation method, the irrigation dosage and frequency should be adjusted so that the electrical conductivity (EC) in the substrate remains stable, and the oxygen concentration is maximized.

Irrigation – Fertigation

The irrigation starts before the water quantity in the bag drops to levels that are not easily available to the plants. **The following equation can be used to calculate the irrigation dose Q** (liters/bag):

$$Q = [N \times Ww \times V] / [1 - dr]$$

Where,

N: is the percentage of easily available water (EAW) in the substrate that, when consumed, should initiate irrigation (1/3 to 1/4 of EAW),

Ww: the content of the substrate in EAW (approximately 85% in mineral wool),

V: the water capacity of the substrate of the bag (liters/bag), which is the amount of water remaining in the substrate after drainage.

To calculate it: weigh the bag with the substrate, add water to saturate it fully, and after saturation, open holes in the bag and let it drain (~6 hours). Then, determine the humidity by weighing the bag again with the substrate (liters/bag), and

dr: the desired percentage of drained water (a drainage percentage of 25-35% is satisfactory; the drainage percentage should be higher when the water's salt content is higher).

Irrigation – Fertigation

The duration of irrigation (*t*) is calculated as the quotient of the irrigation dose (*Q*) and the reciprocal of the product of the number of drippers per bag (*n*) and the flow rate of the drippers (*q*):

$$t = Q / [n \times q]$$

Where,

t: Duration of irrigation (seconds),
Q: Irrigation dose (liters/bag),
n: Number of drippers per bag,
q: ripper flow rate (liters/hour).

Irrigation – Fertigation

The frequency of irrigation is determined by evapotranspiration (which depends on **solar radiation** and plant parameters) and the irrigation dose (which depends on the substrate and the quality of the irrigation water). In cases where the irrigation frequency is controlled by an integral of solar radiation, the **sum of solar radiation** used to initiate irrigation is calculated by the equation:

$$\Sigma Rad = [Q \times \lambda \times (1 - dr)] / (Kc \times etr)$$

- ***ΣRad***: Sum of solar radiation
- ***Q***: Irrigation rate
- ***Kc***: Crop coefficient depending on the growth stage (values 0.8-1)
- *etr*: Percentage of solar radiation consumed by evapotranspiration (values 0.3-0.9, average ≈0.65)
- ***λ***: Latent heat of water evaporation (2.45 MJ/Kg at 20°C)
- ***dr***: Desired drainage water percentage (a drainage percentage of 25-35% is satisfactory; the drainage percentage should be higher as the water salinity increases).

Irrigation: Water Quality

Water suitability for irrigation

Class	EC (dS/m)	Sodium (Na, ppm)	Chlorine (Cl, ppm)
1	<0,5	<30	<50
2	0,5-1,0	30-60	50-100
3	1,0-1,5	60-90	100-150

Water Quality Classifications for Irrigation:

1. **Class 1 Water:**
    1. Suitable for use in all hydroponic systems.
    2. Generally suitable for almost all types of crops.
    3. Represents high-quality water with minimal or no adverse effects on plants.
2. **Class 2 Water:**
    1. Generally acceptable, but some sensitive crops may face issues.
    2. Can be used for various irrigation purposes, but caution is advised for specific plant types.
    3. Considered of good quality but may have certain limitations.
3. **Class 3 Water:**
    1. Has adverse effects on hydroponics.
    2. Recommended to be avoided in closed irrigation systems.
    3. May cause significant issues for plants and is not ideal for most cultivation practices.

Irrigation: Water Quality

A water chemical analysis should include the concentrations of all inorganic dissolved components related to plant nutrition. Additionally, the total electrical conductivity (EC) and the pH of the water should be determined. The most common ions in saline waters are Na^+ and Cl^-, but ions such as Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-, as well as boron (B), can often be present in high concentrations.

The **total electrical conductivity** (**EC**; dS/m) provides an initial approximation of the overall salinity of irrigation water. For most cultivated fruit and vegetable crops, the EC of nutrient solutions should range between 1.5-2.5 dS/m.

The **pH** of the water is determined by various chemical reactions and equilibria among the dissolved ions within it. Optimal pH values for optimal growth and production are between the range of 5.5 – 6.5.

Interactions between the mineral nutrients

The ratio of cation-anion absorption affects the pH of the external solution.

1. Excessive **absorption of anions** (e.g., NO_3^-, $H_2PO_4^-$, SO_4^{2-}) increases the pH of the external solution, while excessive absorption **of cations** (e.g., K+, Ca^{2+}, Mg^{2+}) decreases it.
2. **Nitrogen** in the form of $\mathbf{NO_3^-}$ or $\mathbf{NH_4^+}$ undergoes **competitive relationships**, such as NH_4×Ca, NH_4×Mg, NH_4×K, NO_3×P, and NO_3×S.
3. Potassium (**K**) limits the rate of **Ca** and **Mg** absorption, while at low concentrations, $\mathbf{NH_4^+}$ competes with **K**.
4. Therefore, maintaining a **balanced ratio of macrocations (K: Ca: Mg)** can minimize the occurrence of normal disorders, such as blossom-end rot in tomato, pepper, and strawberry fruits.
5. Mg competes with Mn, and similarly, Cu competes with P, K, and Fe.
6. Additionally, high concentrations of P in the solution should be avoided in case of an increase in EC, as it may lead to toxicity or create a deficiency in Ca or trace elements such as Zn.
7. The use of large amounts of sulfates (SO_4^{2-}) through, for example, potassium sulfate, can create insoluble Ca compounds in the roots.

Interactions between the mineral nutrients

8. Competition is also observed between NO_3^- and Cl^-, where NO_3 absorption is restricted by Cl^-
9. Trace elements, especially Fe, Mn, Zn, Cu, compete both among themselves and with macroelements.
10. Additionally, sufficient plant supply with Ca through the nutrient solution can significantly contribute to minimizing the adverse effects of salinity in hydroponic cultivation.
11. Usually, when optimal relationships between elements are mentioned, they refer to their relationships in the root zone (substrate).
    For tomatoes, the following relationships are reported:
    N:K ≈ 2,
    K:Ca ≈ 1, and
    Ca:Mg ≈ 2.2 (mol/mol).

    To achieve these ratios in the root zone, the nutrient solution should have the following relationships:
    N:K ≈ 1.5, K:Ca ≈ 1.6, and Ca:Mg ≈ 3.5 (mol/mol).

Leaf tissue mineral analysis

Leaf tissue mineral analysis

A method for assessing the nutritional status of plants is leaf sampling, where the results reflect the nutritional condition of the crop during a specific period.

To obtain a representative sample, certain basic principles must be followed, such as:

1. Selection of the **appropriate plant part**, depending on the type of crop, such as: shoot, blade, top, or other plant segment.
2. The sample must be **representative**, and the **number of plants** from which it is taken should be sufficient.
3. Proper **timing** and **stage of crop** development.
4. The sample should come from various plants of the same growth, species, variety, and never should there be a mixture of leaves from related or dissimilar crops.
5. Sampling should be done **on the fourth to fifth leaf from the top (25-40 leaves)** or composite leaves outside the stem, **the 4th – 6th fully developed** during the cultivation period.

Range of optimal sufficiency of nutrient elements in various greenhouse crops

Crop	N%	P%	K%	Ca%	Mg%	Fe ppm	Zn ppm	Mn ppm	Cu ppm	B ppm	Mo ppm
Tomato	3.5-5.0	0.35-0.75	3.5-6.5	2.0-4.0	0.35-0.8	80-200	30-100	100-300	7-20	30-80	>0.4
Cuccumber	3.5-5.5	0.35-0.8	3.0-5.0	2.0-10.0	0.4-0.8	80-200	40-100	100-300	7-17	30-80	1.0-2.0
Lettuce	3.5-5.5	0.5-0.8	5.0-10.0	1.0-2.0	0.25-0.50	80-300	30-300	50-200	5-15	30-80	>0.15
Pepper	3.0-5.0	0.2-0.7	3.5-4.5	1.3-2.8	0.3-1.0	60-300	20-200	50-250	6-25	25-75	0.2-1.0
Eggplant	4.0-5.0	0.29-0.6	3.5-5.0	1.0-2.5	0.3-1.0	50-300	20-250	40-250	5-10	25-75	-
Strawberry	2.5-4.0	0.26-1.0	1.3-3.0	1.0-2.5	0.25-1.00	50-200	20-200	50-200	6-50	23-50	0.5-1.0
Beans	3.0-6.0	0.25-0.75	1.8-4.0	1.0-3.0	0.25-1.0	50-400	20-200	30-300	5-30	20-75	1-5
Zucchini	4.0-6.0	0.3-0.5	3.0-5.0	1.2-2.5	0.3-1.0	50-200	20-200	50-250	10-25	25-75	-
Melon	4.0-5.0	0.25-0.8	3.6-5.0	2.3-3.2	0.35-0.80	50-300	20-200	50-250	7-30	25-60	-
Watermelon	2.5-4.5	0.25-0.7	2.5-4.5	2.0-3.5	0.5-1.0	40-200	20-100	50-250	5-12	30-80	0.5-1.0

Nutrient deficiencies

Depending on the **location of symptoms** on the plant, nutrient deficiencies are classified into **two categories**:

1. In deficiencies of the first category, symptoms are first observed in the lower leaves of the plant and over time progress upward to the middle or top leaves. Such deficiencies include **nitrogen**, **phosphorus**, **potassium**, and **magnesium**.
2. The second category includes deficiencies where symptoms are initially observed in the top leaves and then progress downward. Deficiencies in this category include **calcium**, **boron**, **manganese**, **copper**, and **iron**.

Based on their mobility within the plant, elements are categorized into four groups:

1. ***mobile*** (nitrogen, potassium, sodium),
2. ***moderately mobile*** (phosphorus, chlorine, sulfur, magnesium),
3. ***partially mobile*** (zinc, copper, manganese, iron, molybdenum), and
4. ***immobile*** (boron, calcium).

Practical Tips

i. Before installation

1. **Analysis of available water**. Its electrical conductivity (**EC**) should not exceed 1.5 dS/m. The water content of boron and other trace elements should not exceed double the ideal quantity for plants.
2. Proper design of the irrigation system is necessary to achieve uniform distribution at all points of application. The **minimum water supply per drop should be 1.5 liters/hour**.
3. The irrigation system should **not include metallic parts**, as acids may corrode them, and it should ensure consistent water supply at all points in the greenhouse.
4. Protection of main water pipes from extreme environmental temperatures (insulation, isolation, etc.). The **irrigation water temperature should range between 15°C - 30°C (optimal 20-25°C)**.

Practical Tips

i. Before installation

5. The **slope of the soil should be less than 1.5% (optimal 0.5-1.0%)**. The soil is covered **with plastic mulch**.
6. The grower must be **familiar with the operation of the irrigation programmer** and other systems used in hydroponic cultivation.
7. **Cleaning of the irrigation network** once a year using acid (nitric acid 3-5%) or chlorine (not together). Followed by flushing with clean water.
8. **Disinfection of the greenhouse** space (e.g., 1 part chlorine to 9 parts water).
9. **Calculation of substrates and seedlings needed** (e.g., tomato, 10,400-16,000; cucumber, 5,600-8,000; pepper, 10,00-10,800; melon, 6,800-8,00; green beans, 16,000-36,000 per Acre).

Practical Tips

ii. Before transplanting

1. Use healthy propagation material. Seeds germinate in pre-germination cubes. The goal is to transplant **healthy and robust seedlings**.
2. In the initial filling of perlite substrates, a nutrient solution with a pH of 5.0 is applied. The lowest water pH that can be applied is 4.5. After the initial filling, **the pH is adjusted back to 5.5. Substrates should remain saturated for twenty-four hours**.
3. Substrates should be positioned to ensure **proper drainage**. Two <u>vertical drainage cuts in the plastic cover</u> of the substrates should start from the contact point of the substrate with the ground and have a length of 3-4 cm. Cuts should not be made under the plant.
4. Adequate **watering of both the substrate and the seedlings in the pre-germination cubes before transplanting**. The planting points on the substrate surface should also be well-hydrated.
5. **Avoid transplanting during extreme temperatures**. If necessary, plant hardening should precede transplanting.
6. For large seedlings, thinning should be done before transplanting for hardening.

Practical Tips

iii. After transplanting

1. **Minimum supply per dripper per irrigation: 150-180 ml**.
2. **Never use water alone without a nutrient solution for irrigation** in hydroponic cultivation. The irrigation principle is "little and often." On average, the **irrigation frequency is at least every 60 minutes and at most every 85 minutes**.
3. **Do not use substrates for more years than their specifications allow**, as proper EC regulation becomes challenging, leading to fertilizer wastage due to increased runoff.
4. Substrate **runoff should be equal to or greater than 20%,** increased during midday hours. Therefore, irrigations should be more frequent around noon.
5. **Moisture in rockwool should not be less than 50% (optimal 60-75%)**. When vegetative growth is required, rockwool humidity should range between 70-75%, while for flowering, it should be 60-65%.
6. **pH**, **EC**, **runoff**, and **moisture** measurements in the substrate are valuable when **systematic**, records are maintained, and evaluations are conducted. The EC in the substrate should be at most one unit higher than the drip solution and should not have significant fluctuations during the twenty-four hours.

Practical Tips

iii. After transplanting

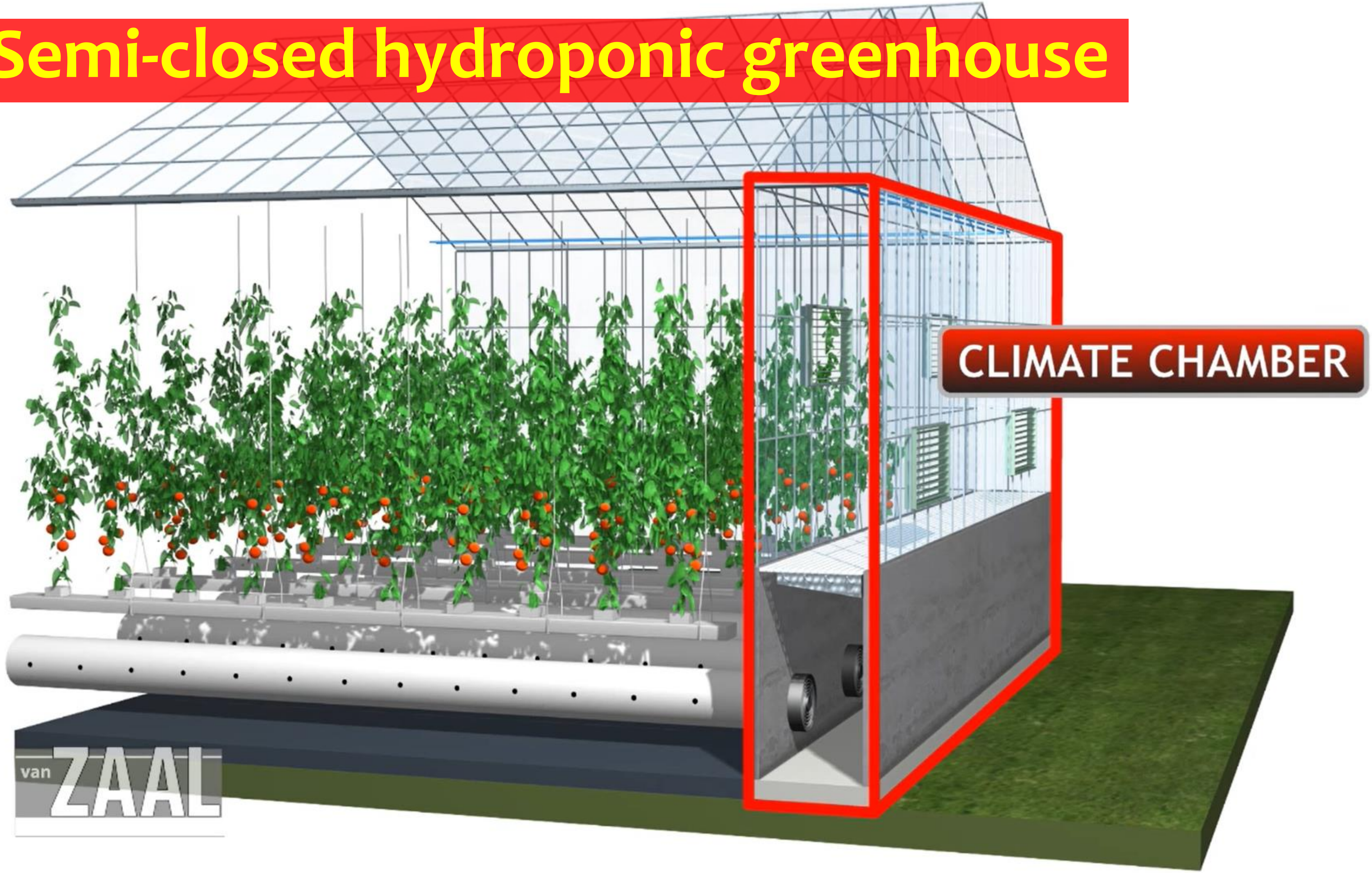
7. **Measurements in substrates** should be distributed throughout the greenhouse, taken at the same **time (7:00-8:00 in the morning)**, from the same substrates each time, and at least three times a week.
8. pH and EC sensors should be replaced and checked according to their specifications.
9. During the summer due to the high transpiration of plants, it is advisable to reduce the EC of the irrigation water. **Higher moisture levels in the slabs during the summer months**.
10. **If the EC value in the substrate is low** due to increased nutrient needs of the plants, **we increase (≈10%) all nutrients**, except for ammonia and phosphorus.
11. The pH in the substrate should range between 5.5 – 6.5. To lower the pH in the substrate, triple the quantity of nutrient solution in one irrigation, performing the so-called "leaching."
12. **Mineral analyses** in the solution are essential at critical stages of cultivation, maximizing the plant's supply and during harvesting for potential corrections. The nutrient solution is taken **before the first irrigation**.

Practical Tips

iii. After transplanting

13. The **nutrient formulation** is always based on the **analysis of the available irrigation water**. When the water source or composition changes, the formulation should also change. Check if the composition of fertilizers and trace elements used is the same as those indicated in the recipe. **Pay attention to the preparation of nutrient solutions**.
14. **Start and end irrigations** cycles **1.0-1.5 hours after sunrise and before sunset**.
15. During periods of **high solar radiation and temperature levels**, night irrigation is recommended.
16. The general guideline is to **maintain plants in balance (leaves/fruits)** and avoid abrupt changes in the root system.
17. Normal to high EC can prevent fruit cracking (e.g., tomatoes) and improve their quality. Higher EC partly leads to smaller fruits with slower growth.
18. **Irregular irrigations negatively affect both yield and fruit quality**.
19. **Increased irrigation rates increase the risk of fungal attacks on the fruit**.

Semi-closed hydroponic greenhouse

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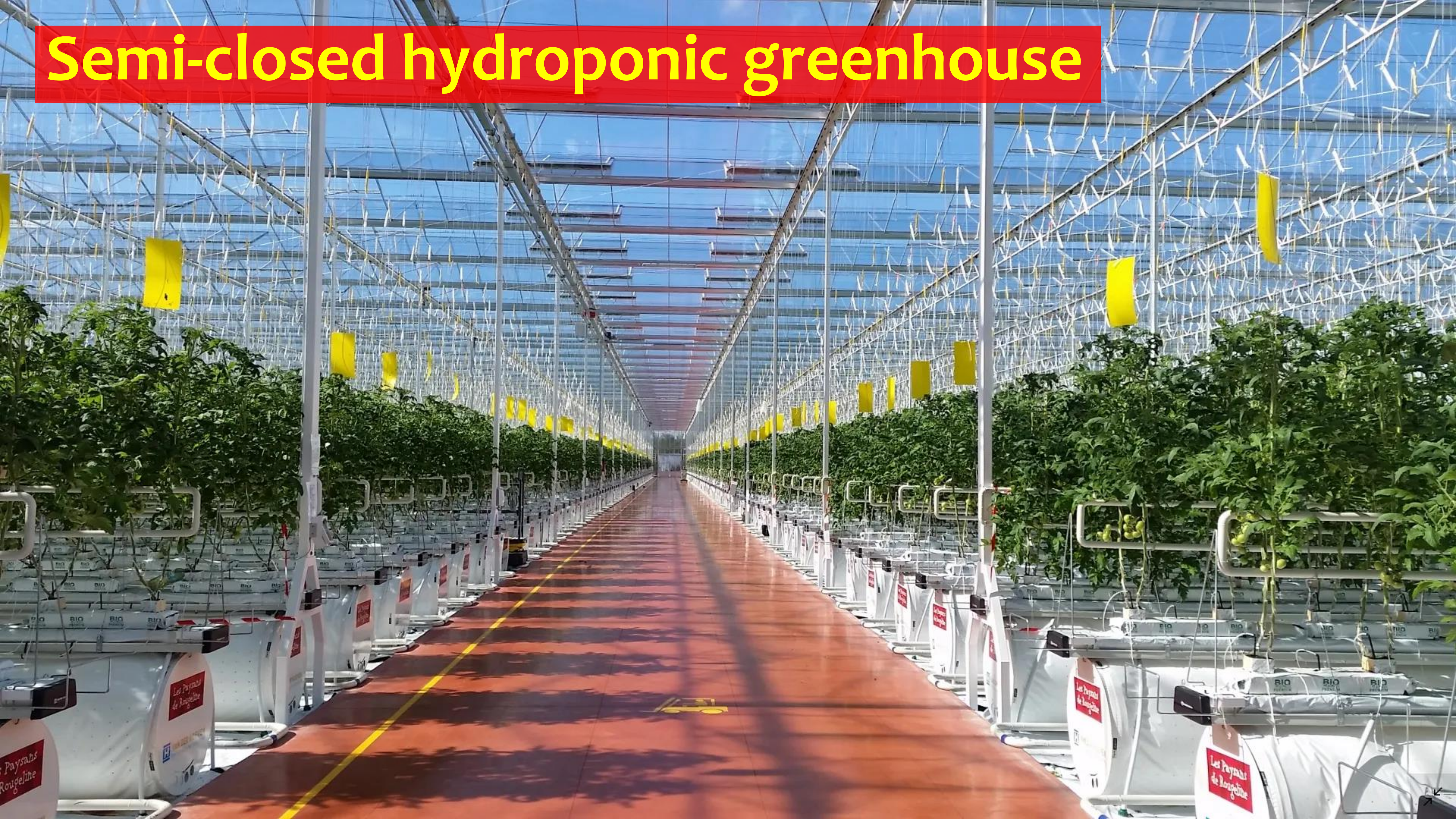
Semi-closed hydroponic greenhouse



Nutrient & irrigation management practices for greenhouse vegetables production

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