HYDROPONICS FARMING TECHNOLOGY- A SKILLING PROGRAM

TRAINING MANUAL

DEPARTMENT OF AGRICULTURE

Ministry of Agriculture and Forests

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SESSION-1(3 Days Programs)

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1 PRINCIPLES AND CONCEPTS OF HYDROPONICS TECHNOLOGY

1.1.Background

In Bhutan, farmers practiced integrated farming system. Crops were cultivated for self-sustenance. There were less technology options for crop cultivation, farming was labour intensive and crop productivity was low. Thus, formal agriculture research in Bhutan started in 1982 with the establishment of the Centre for Agricultural Research and Development (CARD) at Bajo in Wangdue to generate sustainable agriculture technologies for enhancement of crop productivity. Over the years, the national agriculture research system generated technologies that include better performing crop varieties, improved farming methods, efficient pest and disease control measures, interventions into postharvest and water management, and progressive extension education and rapid services.

In pursuit of making agriculture farming more productive, profitable and prestigious and as the agriculture farming shifts from subsistence farming to commercial farming, demand for precision farming, knowledge-based farming, technology-based farming and science-based farming has been increasing over the years.

In Bhutan, hydroponics system is one of the agriculture technologies introduced by the Department of Agriculture recently in the beginning of 2019. Currently, Department of Agriculture has established four hydroponics systems at ARDC Bajo, ARDC Samtenling, ARDC Wengkhar and NCOA Yusipang.

1.2.What is hydroponics?

Hydroponics is the soilless method of growing plants, using nutrient solutions. The word hydroponic is derived from the Greek words, *hydro* (water) and *ponos* (labor), literally meaning water working.

1.3. Why go for hydroponics?

- Year-round production
- Gender-friendly technology
- Produce more from a small area
- Decreased pest and disease incidence
- Increase peri-urban agricultural production
- Produce safe food
- Reduce weed growth
- Reduce drudgery
- Efficient use of water and nutrients
- Efficient use of space as it involves vertical cultivation
- High value crops

1.4. Challenges of hydroponics

- High initial investment cost
- Technical skill and knowledge are necessary for operating the system
- Requires strict sanitation to avoid pest and disease incidence
- Daily monitoring is necessary

1.5. Basic components of hydroponics systems

Components of hydroponics system may differ depending upon the system adopted. Following are the basic components in a hydroponics system.

- **Nutrient solution:** It is the solution prepared by dissolving all the nutrients required for plant growth in water.
- **Nutrient solution reservoir:** It is a structure/ container that hold the nutrient solution.
- **Pump:** It is an electric device that circulates nutrient solution through the distribution network and supplies oxygen to the nutrient solution.
- **Growing medium:** A growing medium is a substrate that provides support to the plants.
- **Growth chamber:** It is a structure that holds nutrient solution and plant such as pots, troughs, trays, PVC pipes etc.,

1.6.Requirements for crop growth and development

Whether plants are grown hydroponically or in soil, several factors affect plant growth.

- **Nutrition:** Plants require different nutrients for proper growth and development. Plants grown in soil receive much of the nutrients from soil. However, in hydroponics, all the nutrients that plants require should be made available to them in a balanced nutrient solution. If plants do not receive their requirement, they exhibit deficiency symptoms such as yellowing, stunted growth etc.,
- **Air:** Oxygen and carbon dioxide play a vital role in crop growth and development. Oxygen is critical for respiration in all living beings. In media free hydroponics, supply of oxygen through the use of an oxygenator is essential.Carbon dioxide plays an important role in biomass production as more than 90% of dry matter of living plants is derived from assimilation of CO_2 during photosynthesis. Plant uses carbon from CO_2 and convert it into carbon compounds such as glucose, carbohydrates and cellulose which is called plant biomass. Therefore, increased level of CO_2 in the hydroponic growth chamber there will be increased rate of photosynthesis which will also increases the rate of biomass production of the plant.
- **Light:** Light is an essential factor for the process of photosynthesis. The quality, duration and intensity of light can have different effects on plant growth. Plants are classified into short day, long day and day neutral plants according to their light requirements. Many lighting equipment are available in the market that enables manipulation of light requirement.
- **Water:** Plant roots absorb water from the soil and use it to maintain cell structure and other important metabolic processes. In hydroponics, plants are provided with water directly through the nutrient solution.

- **Temperature:** The temperature, relative humidity and air flow can also affect plant growth. The rate of photosynthesis is dependent on the temperature. Rate of photosynthesis drastically decreases above 35 ºC. In protected structures, equipment such as exhaust fans and heaters can be used to manage temperature. Changes in temperature affect availability of dissolved oxygen in water. Optimum water/nutrient solution temperature is 18 to 27 ºC.

1.7. Types of hydroponics system

Hydroponics is classified into several categories based on the following factors:

1.7.1. Based on use of medium

A system may or may not use medium (substrates) for holding plants and a hydroponics system is classified into two based on use of medium.

- **Medium-based hydroponics**

  Under medium based hydroponic systems, crops are grown in different substrate/media which are used for anchoring the plants while nutrient is supplied from a separate nutrient reservoir tank.

  Advantages

  - Retains moisture
  - Anchor plants

  Disadvantages

  - Most mediums can only be used once
  - Costly (to buy, transport)
  - Not readily available

  Types of substrates

  - **Oasis cube** are made of foam.
  - **Rice husk biochar** is produced by low temperature pyrolysis of rice husk.
  - **Rockwool** is a lightweight hydroponic substrate made from spinning molten basaltic rock into fine fibers which are then formed into a range of cubes, blocks, growing slabs and granular products.
  - **Vermiculite** is a media made from a natural mineral that expands with the application of heat. It is very lightweight and sterile.
  - **Soilrite** is a mixture of horticulture grade expanded perlite, peat moss and exfoliated vermiculite in equal ratio i.e., 1/3:1/3:1/3.

- **Wood chips** are small- to medium-sized pieces of wood formed by cutting or chipping larger pieces of wood such as trees, branches, logging residues, stumps, roots, and wood waste.
- **Expanded clay** is a light weight aggregate made by heating clay to around 1200 °C in a rotary kiln.
- **Coco peat** is a growing medium made from the husks of coconuts.
- **Pine bark chips** are shredded or chipped pieces of pine tree bark.
- **Rice husk** are the hard protecting coverings of grains of rice.
- **Gravels** are a loose aggregation of rock fragments.
- **Mosses** are small, non-vascular flowerless plants that typically form dense green clumps or mats, often in damp or shady locations.

a. Rockwool


b. Vermiculite and soilrite mixture


c. Wood chips


d. Expanded clay


e. Cocopeat

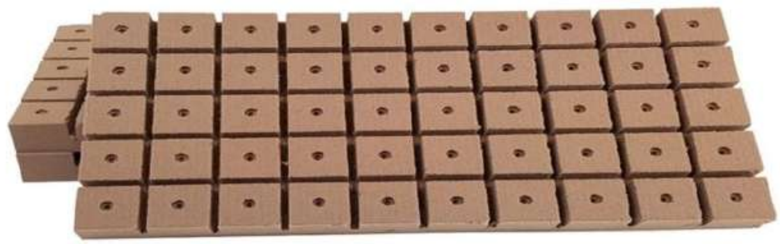

f. Pine bark chips

g. Rice husk

h. Moss

i. Gravels

j. Rice husk biochar



k. Oasis cube

Figure 1. Different substrates/media

Suitable crops grown in different medium/substrates as shown in *table 1*.

Table 1. Crops suitable for different medium/substrates

Vegetables	**Fruit crops**
Tomatoes	Strawberries
Lettuce	Raspberries
Egg plant	Blueberries
Leafy greens	
Melons	
Cucumber	
Peppers	
Kale	
Ginger	
Turmeric	
Beans	
Onion	

- **Medium-free hydroponics**

  No medium is used in medium-free hydroponics and the plant roots remain in direct contact with the nutrient solution.

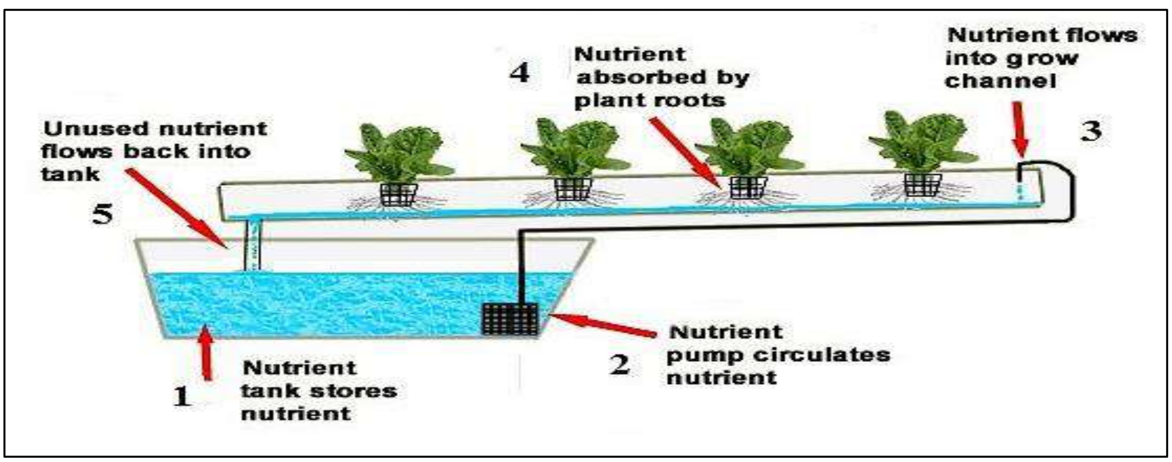
1.7.2. Based on growing techniques

Hydroponics systems are classified into five broad categories based on the growing technique used as follows:

- **Nutrient Film Technique (NFT)**

  A very shallow stream of nutrient solution is recirculated past the bare roots of plants in a watertight gully, also known as channels with the help of a pump. The channels have holes on top in which net cups holding the plants are inserted. The roots are not completely submerged in the channels.

  Usually, the nutrient solution is circulated continuously. However, the nutrient solution can also be circulated on an intermittent basis by allowing flow for a few minutes and stopping flow for 15-60 minutes to improve aeration. This system is usually used for growing small leafy greens and herbs as shown in *figure 2.*

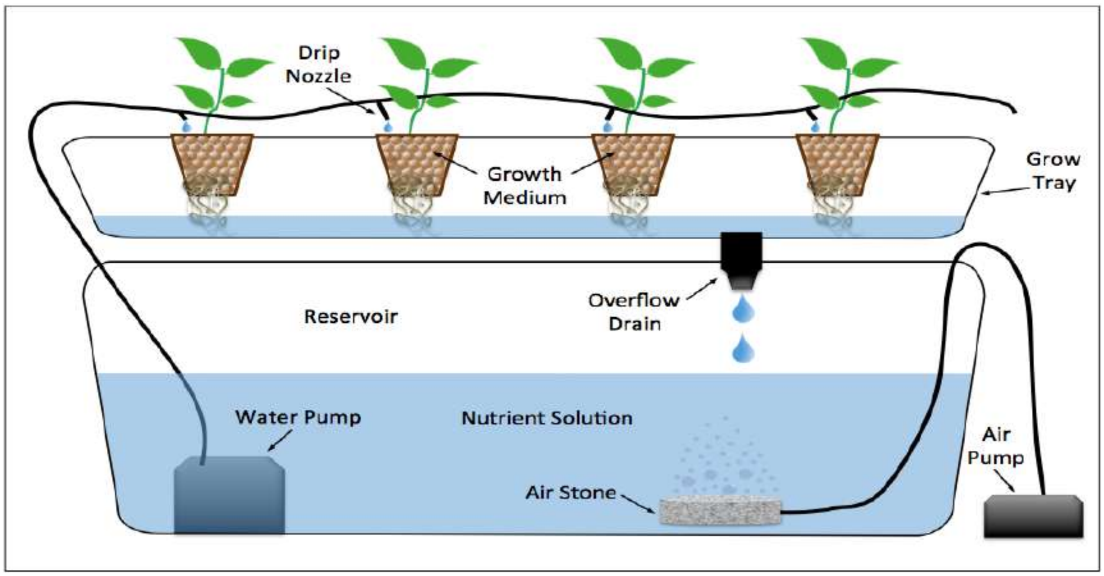


Source: Addloes Lighting & Hydroponics

Figure 2. Diagrammatic representation of NFT system

- **Drip hydroponics technique**

Plants are planted in bed, bag or pot substrate systems and the nutrient solution is distributed through individual drippers or emitters directly to the root zone. This technique allows the operator to control the amount of water applied. This technique is suitable for growing larger plants such as cucurbits and solanaceous crops as shown in *figure 3.*

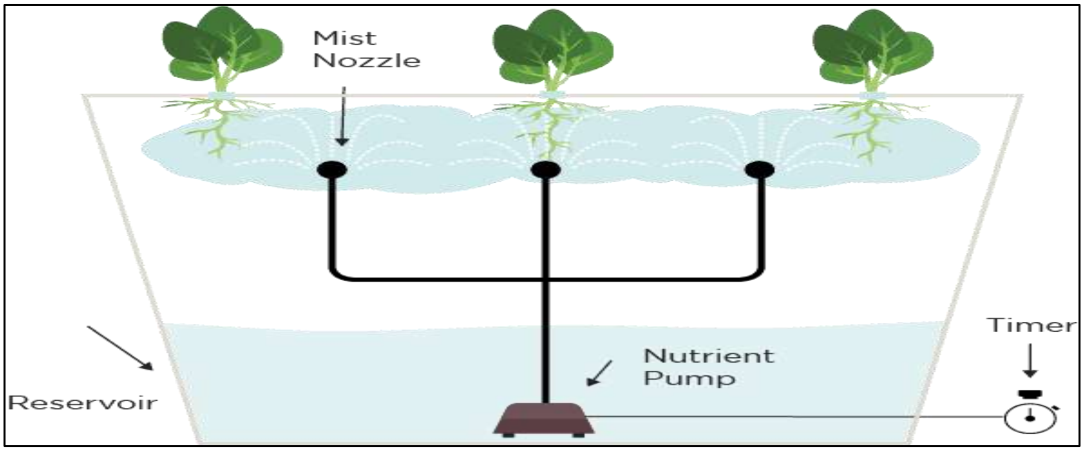


Source: Off-Grid Gorilla

Figure 3. Diagrammatic representation of drip irrigation technique

- **Aeroponics technique**

It is a system where the roots are continuously or discontinuously in an environment saturated with fine drops (a mist or aerosol) of nutrient solution within a chamber. The plants are anchored into Styrofoam panels. A pump pushes oxygen rich nutrient solution through misters or foggers, keeping the roots wet. This technique is excellent for growing low leafy vegetables as well as potato. It is shown in *figure 4.*



Source: Trees.com

Figure 4: Diagrammatic representation of aeroponics technique

It is of two types:

- **Root mist technique**

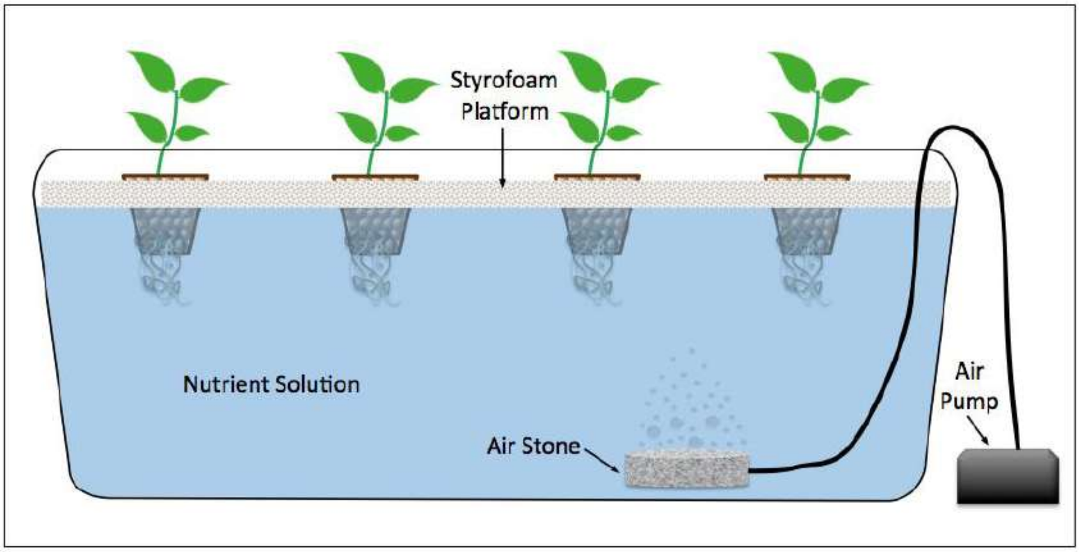
  Nutrient solution is sprayed or misted on to the roots in growing chambers where roots are suspended in air. It is used in vertical grow tower systems.

- **Fog feed technique/ Fogponics**

  It uses a suspension of nutrient enriched water to deliver nutrients and oxygen to the plant's roots and a number of mechanisms (for example ultrasonic, compressed air, or heating elements) to form a suspension of much smaller particles of water (5–30 µm), or even as vapors.

- **Deep Water Culture Technique**

Well-rooted plants are placed in net pots on a floating plate in the nutrient reservoir. To stabilize the plant, the net pot may be filled with substrate, e.g., clay balls or oasis foam. The roots hang directly in the nutrient solution, which is oxygenated by means of an air pump and aeration stones. The system is simple and safe as shown in *figure 5*. Due to the large water reservoir, you can leave the system alone for a few days without having to worry about it in the event of power outage.

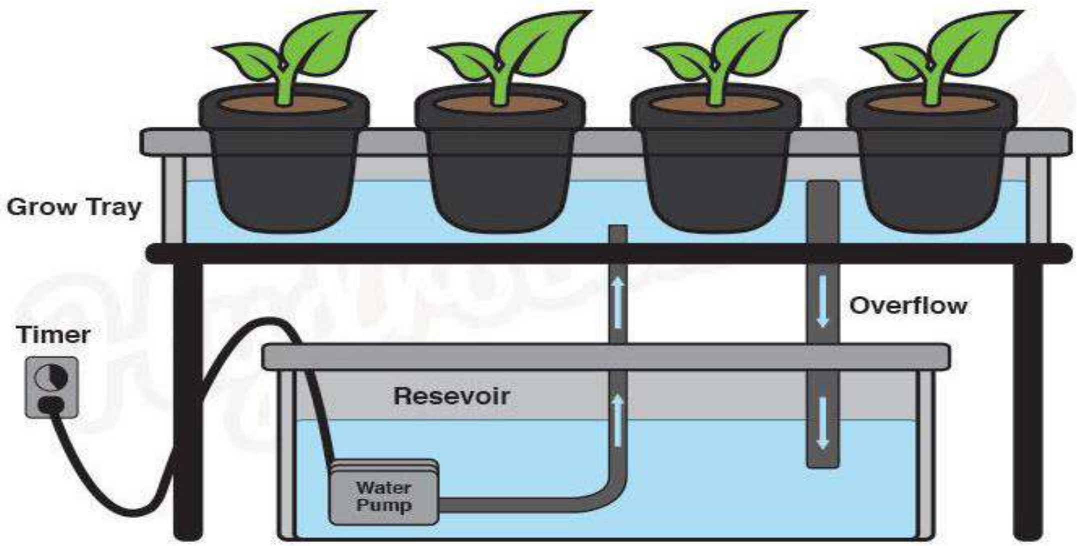


©Off-Grid Gorilla

Figure 5: Diagrammatic representation of Deep-water culture technique

- **Ebb and flow/ flood and drain technique**

A reservoir containing nutrient solution is located below a growing tray. Periodically, the growing bed is flooded by a small pump on a timer to feed and water the plants. When the timer switches off, the nutrient solution drains back into the tank, which sucks oxygen into the root zone. An overflow drain adjusts the nutrient fill height and ensures the system does not overflow. A residual amount remains to make the system less vulnerable if the pump should fail. It is easy to set up and use. In addition to commonly grown crops in hydroponics, root, bulb and tuber crops are also grown in this system as shown in *figure 6.*



Source: Hydrobuilder

Figure 6: Diagrammatic representation of ebb and flow technique

1.7.3. Based on nutrient solution use

Based on how the nutrient solution is used, hydroponics systems can be classified into two systems as follows:

- **Closed/recovery/re-circulating systems**

In this system, the nutrient solution is passed through the roots and collected in the reservoir for reuse. The concentration of nutrients circulating in the system decreases as the plants use it and hence, such systems require regular replenishment of nutrients. If the nutrient solution comes in contact with any disease-causing organism, the whole system will be infected unless the system is cleaned and the nutrient solution replaced. It is shown in *figure 7*.

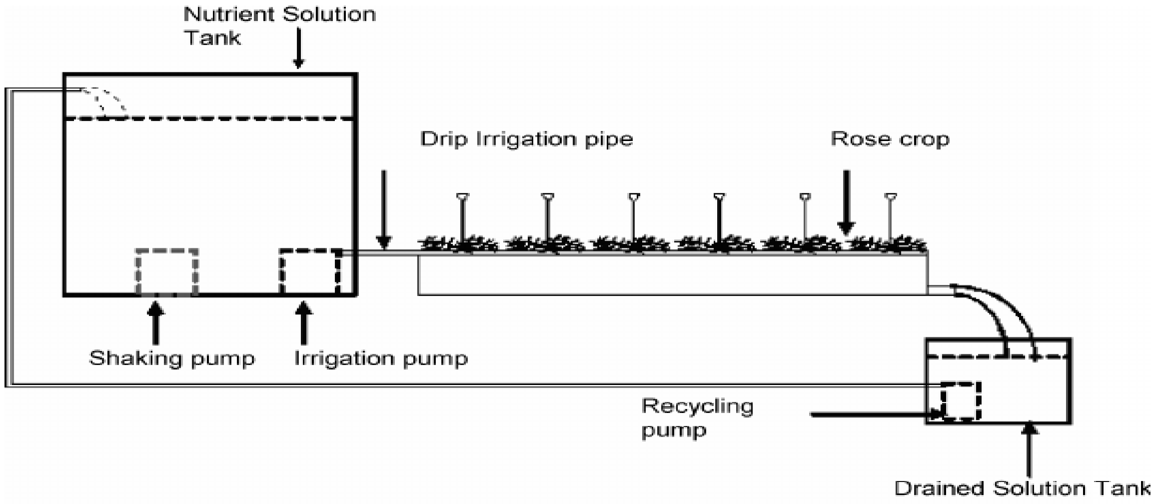


Figure 7. Closed system

- **Open/ non-recovery/ non- recirculating systems**

The nutrient solution is passed through the plant roots and discarded. It is not collected for reuse. This system results in wastage of nutrient solution since the rate of flow is greater than the rate of uptake of nutrients by plant roots. It is shown in *figure 8.*

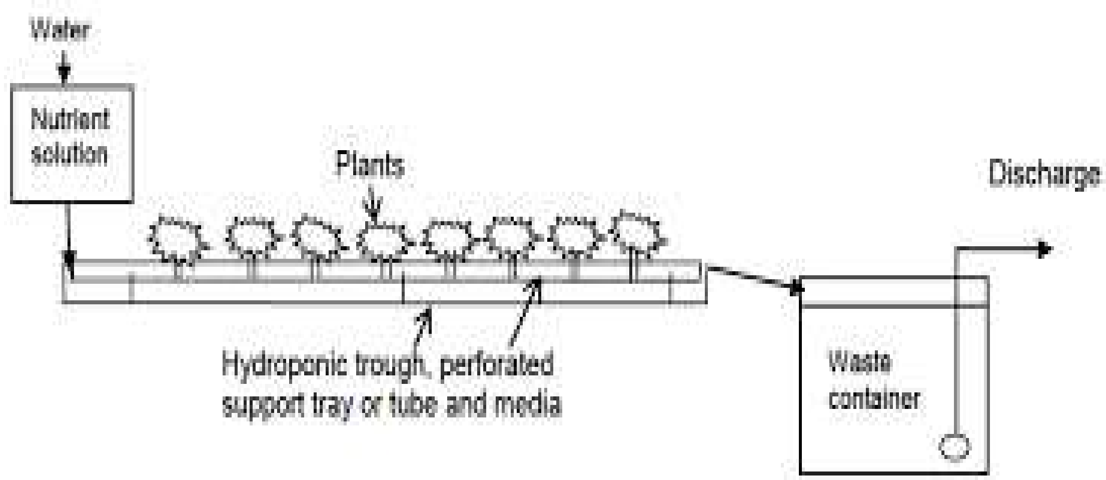


Figure 8. Open system

1.7.4. Based on nutrient solution distribution

Nutrient solution distribution in a hydroponics system is of two types. They are:

- **Active system**

Any hydroponics system which utilizes electricity for operation is considered an active system. With emergence of sophisticated technologies such as pumps, nutrient sensors, nutrient flow regulators, lighting equipment etc., active systems are widely recommended for commercial use.

- **Passive system**

The movement of nutrient solution aided entirely by gravity constitutes the passive hydroponics system. Passive hydroponics systems are nearly obsolete with advancement in technology.

1.7.5. Based on space utilization

- **Vertical system**

It is defined as any type of support or structure that is used to grow plants up and off the ground as shown in *figure 9*. It accommodates more number of plants per unit area since the system utilizes vertical space and is suitable for growing small plants like strawberry and herbs.

Figure 9. Vertical system

- **Horizontal system**

  It is a practice of cultivating crops, vegetables etc. in horizontal cultivable area without any restriction of height as shown in *figure 10*. It accommodates less number of plants per unit area and suitable for growing larger plants like tomatoes, chilies and cucumber.

Figure 10. Horizontal system

1.8.Suitable crops for hydroponics

Leafy vegetables like lettuce, spinach, kale, mustard greens and herbs like celery, parsley, chives, coriander and basil are found to be the most convenient and lucrative crop grown under hydroponic systems. Fruits like strawberry, cucumber and vegetables like tomato and chili are also grown.

1.9.Companion cropping

In hydroponics systems, plants having similar pH and EC requirements are usually grown together. Lettuce with herbs like chives and coriander helps in controlling aphid infestation. Celery, parsley, basil and lettuce can also be grown together as companion plants in hydroponics as shown in *figure 11*.

Figure 11. Companion cropping of lettuce, parsley and basil in NFT system

1.10. Nursery

Nursery is a place where young plants are grown from the seeds using different media in a protected area and make it ready for plantation in the hydroponics system.

- Nursery must fulfill the following needs
  - Seed must be from the clean source
  - Nursery area must be in a protected space with ventilation facilities to avoid the pest & disease infestation
  - Irrigation water and light must be available
  - Suitable growing media

1.11. Transplanting seedlings in hydroponics system

From the nursery, the healthy seedlings are transplanted at 2-3 leaf stage in the hydroponics system, if the nursery is raised in oasis cubes and rockwool. However, if the nursery is raised in other growing media, the seedlings are first uprooted, washed, treated with broad-spectrum fungicides, placed in the sponge. These are then placed in the netted cups and planted in the system.

1.12. Harvesting

Harvesting in hydroponics is no different than harvesting in traditional farming. In general, vegetable crops are perishable and their shelf life and quality depend on a number of actions such as:

- Picking at the right stage without damage
- Picking early in the morning or when it is cool
- Keeping the produce in a cool place after harvest
- Handling carefully
- Storing them at the right temperature
- Using the right packaging method depending on crop and intended market

SESSION-2 (4 Days Programs)

(Trainers: Mr.Suraj Chettri & Mr.Tashi Wangchuk, NSSC Semtokha)

2. PLANT NUTRIENT SOLUTIONS

2.1.What is Plant Nutrition?

Plant nutrition is defined as the supply and absorption of chemical compounds required for plant growth and metabolism. Plant requires 17 essential nutrients and some beneficial nutrients for their growth and development which is broadly categorized into macronutrients, micronutrients and beneficial nutrients as shown in *table 2*.

- **Macronutrients**: Those nutrients required by the plants in large amounts.
- **Micronutrients**: Those nutrients required by the plants in small quantities.
- **Beneficial Nutrients**: Those nutrients which are shown to exert beneficial effects on plant growth at very low concentration.

Table 2. Plant nutrients

Macronutrients	Micronutrients	Beneficial Nutrients
Carbon (C)	Iron (Fe)	Silicon (Si)
Hydrogen (H)	Zinc (Zn)	Vanadium (V)
Oxygen (O)	Copper (Cu)	Cobalt (Co)
Nitrogen (N)	Boron (B)	Aluminum (Al)
Phosphorus (P)	Molybdenum (Mo)	Sodium (Na)
Potassium (K)	Chlorine (Cl)	Selenium (Se)
Calcium (Ca)	Manganese (Mn)	
Magnesium (Mg)	Nickel (Ni)	
Sulphur (S)		

2.2.Functions of macronutrients

- **Nitrogen**
  - Vital for vegetative growth.
  - Improves the quality of leafy vegetables by increasing protein content.
  - It is an important component of protein and enzyme.
- **Phosphorus**
  - Promotes early root formation and growth.
  - Essential for cell division.
  - It improves quality of seed grain.
- **Potassium**
  - It is necessary for fruit development and disease resistance.
  - Enhances crop quality and shelf life of fruits and vegetables.
  - Plays a major role in transport of water and nutrients throughout the plant in xylem.
- **Calcium**
  - It increases fruit set and quality.
  - Essential for the formation of cell wall.
- **Magnesium**
  - It improves utilization and mobility of phosphorus for root development.
  - Essential for photosynthesis.
- **Sulphur**
  - It is necessary for seed formation.
  - It is an integral part of amino acids and develops enzymes.

2.1.Functions of micronutrients

- Control the uptake of major nutrients.
- Essential component of cell wall.
- Helps in plant growth hormones and enzymes system.
- Helps in converting inorganic phosphate to organic phosphate

2.3.Functions of beneficial nutrients

- Exert beneficial effects on plant growth and plant immunity.

2.4.Types of nutrient solutions

2.4.1. Inorganic based

- **Premix nutrient:** It is a readymade inorganic nutrient which comprises of all essential nutrient elements required for normal growth of plant. The commercially available products usually come in 2 different parts since some nutrients precipitate when mixed in concentrated solution. Part A contains NPK, most of the macro and micro nutrients that dissolves easily. Part B contains calcium nitrate and it is not easily soluble. Premix nutrient from Envirevo Agritech is currently being used for hydroponics in Bhutan as shown in *figure 12.*

Figure 12. Hydroponics Nutrients-Part A & B

- **Formulated nutrients:** Nutrient formulation is prepared by mixing different chemicals or fertilizers which are required by crops for optimum growth. Different nutrient formulations for stock solution based on chemical fertilizers and reagent grade chemicals are developed and being assessed in ARDCs (*Table 3*). Stock solution is further diluted based on the EC and pH requirement of the target crop for actual application of the nutrient solution.

Table 3. Recommended/standard nutrient formulation

Element	Leafy greens & herbs	Fruit vegetables
	ppm	
Nitrogen (N)	156.00	233
Phosphorous (P)	31.000	24
Potassium (K)	210.00	254
Calcium (Ca)	120.000	179
Magnesium (Mg)	24.000	49
Sulphur (S)	33.000	66
Boron (B)	0.1600	0.45
Copper (Cu)	0.0230	0.25
Manganese (Mn)	0.2500	0.5
Molybdenum (Mo)	0.0240	0.01
Zinc (Zn)	0.1300	0.48

Source: Adapted from modified Sonneveld's solution

Table 4. Nutrient formulation based on chemical fertilizers

Element	Leafy greens & herbs	Fruit vegetables
	mg/ litres water	
Mono potassium phosphate (0:52:34)	140	100
Potassium nitrate (13:0:45)	460	600
Calcium nitrate (15.5:18.8)	620	1000
Magnesium sulphate (9.6:13)	250	504
Chelated micronutrient	200	200

Table 5. Nutrient formulation for stock solution based on reagent grade chemicals

Sl. No.	CROP: LEAFY Chemical Fertilizer types	mg/l (ppm)
Solution A (in grams)		
1	Calcium Nitrate [Ca (NO3)2]	607.545
2	Potassium Nitrate [KNO3]	928.62
3	Ammonium Nitrate [NH4NO3]	49.58
4	Ferrous Sulphate [FeS04]	23.81
Solution B (in grams)		
1	Magnesium Sulphate [MgSo4]	240
2	Manganese Sulphate [MnSo4]	1.27
3	Zinc Sulphate [ZnSo4]	0.825
4	Boric Acid [H3BO3]	1.175
5	Copper Sulphate [CuSo4]	0.12
6	Sodium Molybdate [Na2Mo04]	0.125
7	Di-Potassium hydrogen phosphate [K2HPO4]	155

2.4.2. Organic based

- **Premix:** It is a readymade organic nutrient available in the market. *FloraBloom, Hydrogrow and Nutrigrow* are some of the commercially available premix organic fertilizers as shown in figure 13. In future, we will assess the performance of organic premix nutrient solution.

Figure 13. Premix

- **Liquid nutrient formulation:** The nutrient formulation is extracted by fermenting organic wastes such as compost (all types), bio-slurry and vermicompost tea. This formulation will be developed and assessed to promote organic nutrient sources for hydroponics.


Figure 14. Liquid nutrient formulation

2.5.Water quality, pH & EC/TDS required for crops and its importance

- **Water quality:** All hydroponic growing systems require pure water. The best domestic water supplies or water for agricultural use frequently contain substances and elements that can affect (positively or negatively) plant growth. It is advisable to use distilled or reverse osmosis (RO) water. However, in case of non-availability of distilled or RO water, tap water could be used. The pH and EC of tap water should be tested prior to use.

- **pH:** pH is the measure of acidity (H+) or alkalinity (-OH) of the solution. The plant productivity is closely related with nutrient uptake and the pH regulation. Each nutrient shows differential responses to changes in pH of the nutrient solution and may not be available to the plants if the pH is low or high. The optimum pH range of nutrient solution is between 5.5 and 6.5. To maintain optimum pH range, nitric acid is added to lower the pH and sodium hydroxide for raising the pH.

- **EC:** Electrical conductivity (EC) is the measure of a solution's ability to conduct an electrical current. It is measured in micro-Siemens per centimeter. A higher EC means higher salt concentration, while a lower EC means a lower salt concentration. Higher EC hinders nutrient uptake by the plants and lower EC may severely affect plant health and growth. Add nutrient solutions if EC is low and add water if EC is high. Different plants require different pH and EC level (*Table 6*).

Table 6. Optimum pH and EC range for different crops

Plant	pH	EC	
		dS m^{-1}	µS cm^{-1}
Lettuce	5.5-6.5	0.8-1.2	800-1200
Basil	5.5-6.5	1.0-1.6	1000-1600
Hot peppers	5.5-6.5	3.0-3.5	3000-3500
Kale	5.5-6.5	1.6-2.5	1600-2500
Tomato	5.5-6.5	2.0-5.0	2000-5000
Celery	6.3-6.7	1.8-2.4	1800-2400
Capsicum	6.0-6.5	1.8-2.2	1800-2200
Pak-choi	7.0	1.5-2.0	1500-2000
Parsley	5.5-6.0	0.8-1.8	800-1800
Mustard green	5.5-6.5	1.2-2.4	1200-2400
Spinach	5.5-6.6	1.8-2.3	1800-2300

- **TDS-** Total Dissolved Solids (TDS) is a measure of all inorganic and organic substances in the liquid and it is measured in parts per million (ppm). Since the hydroponic nutrients dissolved in the water are all ions, EC can be also used as an indirect measurement of the TDS.
- **Temperature-** The temperature range of 18 ^{0}C to 27 ^{0}C has shown high level of dissolved oxygen for the development of healthy roots and optimal nutrient absorption in the hydroponic system.

Figure 15. Portable pH, EC & TDS meter

2.6.Preparation of nutrient stock solutions

2.6.1. Commercial products (premix)

The premix from Envirevo Agritech comes in two different packets (A and B) of 1 kg each. The procedure for preparation of stock solution is as follows:

- Take 2 buckets and fill with 16 liters of water each.
- Take 2 packets of part A nutrient and mix it in the first bucket and then stir well to mix properly.
- Take 2 packets of part B nutrient and mix it in the second bucket and then stir well to mix properly.
- Stock solutions A and B are ready. Store these stock solutions in a dark and cool place. Use these solutions within 2 months.
- The solutions A and B are mixed in equal amount in the nutrient reservoir tank as per the plant requirement (*Refer table 6*).

2.6.2. Formulated nutrients

Some fertilizer salts and reagent graded chemicals react with each other while some do not react. The fertilizers and reagent graded chemicals that react with each other cannot be mixed together due to the precipitation in the solution. Therefore, select fertilizers that are compatible with each other. The below chart (*Table 7*) indicates the compatibility of the fertilizer salts and reagent graded chemicals solution:

Table 7. Chemical/reagents compatibility chart

Chemical/reagents	Calcium nitrate	Potassium Nitrate	Mono potassium phosphate	Magnesium Sulfate
Calcium nitrate	√	×	×	×
Potassium nitrate	×	√	√	√
Mono potassium phosphate	×	√	√	√
Magnesium sulfate	×	√	√	√

× Non-Compatible √ Compatible

2.6.3. Inorganic formulation

- Use water-soluble fertilizers or reagent grade chemicals containing both macro and micro nutrients.
- Take 2 buckets and fill with 20 liters of water each.
- Add recommended rate of fertilizers/reagent grade chemicals (solution A) in the first bucket and then stir well to mix properly.
- Add recommended rate of calcium nitrate (solution B) in the second bucket and then stir well to mix properly.
- Stock solutions A and B are ready.
- Store these stock solutions in dark and cool place. Use these stock solutions within 2 months.
- These solutions are mixed in water tank as per the plant requirement.

2.6.4. Organic solutions

Bhutan Agri Microbial Solution Fermented Plant Extract (BAMS FPE)

BAMS FPE is made from fresh weeds, ash, fruit and vegetable wastes, and rice bran with BAMS. BAMS FPE contains organic acids, bioactive substances, minerals and other useful organic compounds which are produced or extracted from plants through fermentation process.

Materials required to prepare stock solution

Plant matter (chopped)	: 2-3kg
Clean water	: 14 litres
Molasses	: 420ml (3% of water volume)
BAMS	: 420ml (3% of water volume)
Plastic drum or bucket	: 20L

Process of preparation

- Chop fresh plant materials into small (2-5cm) pieces and place in a container.
- Mix BAMS and molasses in the water and stir to prepare a solution
- Add the solution into the container containing chopped plant materials.

- Cover container with black polythene or vinyl and put lid on top of the black cover and place some weights on it.
- Store the container in a warm place (ideally 20℃ to 35℃), away from direct sunlight.
- Fermentation is initiated and gas is generated within 2-5 days. This depends on the ambient temperatures.
- Stir the liquid in container regularly to release gases.
- BAMS FPE is ready to use 7-14 days after preparing it when the pH of the solution drops below 4.0 (ideally it has a pH around 3.5) and when it has a sweet –sour smell.
- Pour the prepared BAMS FPE into plastic bottles after removing plant materials by filtration.

Figure 16. Raw materials (melia fruit, green leaves and fruits)

Figure 17. Mix in tank with water and other ingredients

SESSION-3 (1 Day Program)

(Trainers: Pema Tshoki, NPPC Semtokha & Thinley Choden,NCOA,Yusipang)

3. PEST, DISEASE AND WEED MANAGEMENT

3.1.Pest, disease and weed management in hydroponics system

One of the advantages of the hydroponics system of growing plants is less incidence of pests, diseases, and weeds. However, this depends on the conditions under which the hydroponics system is established. If water is contaminated, the chance of pest, disease and weed incidence is higher especially for those pests, diseases and weeds that are water-borne. Nevertheless, there can be an occurrence of a few pests, diseases and weeds that are generally related to environmental conditions and the type of water used.

3.2.Common insect pests in hydroponics

In order to protect the plants from pests, correct identification of pests is necessary. Common pests in hydroponics are:

- **Aphids**
  - Also known as plant lice
  - Found in three different colors: green, black, or gray
  - Can be easily spotted anywhere on the plant, but they gather around the stems in huge cluster
  - The leaves turn yellow as the aphids suck the sap/juice out of leaves. This results in weak plants

- **Spider mites**
  - Tiny in size (less than 1 mm long)
  - Common pest found in all indoor gardens
  - Difficult to notice due to their small size
  - It is best to look for spider-like webbing around the stems and leaves or take a soft tissue or cloth

and wipe gently on the underside of leaves. If there are red streaks of blood on the tissue, it shows there are spider mites

- **Thrips**
  - They are also tiny in size (around 5 mm long)
  - They are tough to identify but it is easy to notice the damage done to the crops
  - Keep a look for small metallic black spots on the surface of leaves. The leaves start turning yellow and brown. The leaves will eventually dry out

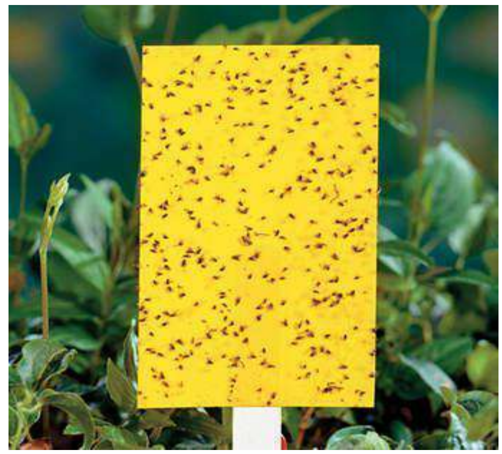
- **Whiteflies**
  - Whiteflies are also small in size (about 1 mm long)
  - White in color and looks like a small white moth
  - They can easily be spotted, but it is hard to kill them because they are agile in nature and flies away to nearby plants when slightly disturbed
  - They cause white spots on leaves. They also suck out plant saps thereby causing plants to dry out

- **Fungus gnats**
  - Adult fungus gnats are not harmful to your plants
  - However, their larvae feed on roots, which can slow down the plant growth, invite bacterial infection, and in extreme cases, they can also cause plant death

3.3.Common insect pest management practices

There are few methods that can be utilized to control the pests but to **prevent their entry in hydroponics system in the first place is the best method** than trying to control their numbers and damage once they have established themselves in the system.

- **Sticky traps**
  - Flying pests like whiteflies, fungus gnats and thrips come in contact with the sticky traps and get glued or trapped to it. This helps in identifying them and makes it easy to get rid of them
  - Yellow sticky trap is the best control method for whiteflies and fungus gnats
  - Blue sticky traps are useful in controlling thrips



- **Beneficial predators (Farmers' friend)**
- **Ladybird beetles/ladybugs-**
  - The use of beneficial predatory creatures like ladybird beetles can assure some level of success in controlling the pests like aphids, thrips, and mites
  - An adult ladybug can eat up to 5,000 aphids in its lifetime. Introduce ladybirds in the hydroponics system to manage aphids

- **Green lacewing** –
  - Also known as aphid lion
  - The larva eats up to 60 aphids in an hour
  - They also feed on other soft-bodied insects such as spider mites, whiteflies, and thrips
  - The adult lacewing is a pollinator

- **Hoverfly/Syrphid fly**
  - Commonly found on flowers and also known as flowers flies
  - The larval size varies in length from 1-13mm
  - The larva eats soft-bodied pests like aphids

3.4.Use of organic and inorganic pesticides

- **Organic/bio pesticides-** Neem oil, artemisia and jholmol (4ml/L) are effective in controlling aphids and loopers
- **Inorganic pesticides-** Chlorpyrifos 20 EC (4ml/L), malathion 50 EC and cypermethrin 10 EC (1ml/L) are effective in controlling aphids, thrips, whiteflies, spider mites and many other pests. It is important to alternate the pesticides, since pests develop resistance rapidly

3.5.Common diseases in hydroponics

The most common hydroponics plant diseases are;

- **Root rot**
  - When there are too much water and pathogens in the growing medium, it can result in root rot of your plants
  - Root rot is a fungal disease caused by a variety of fungi
  - Plant's wilt and turn yellow. Roots can get mushy too resulting in weak plants

- **Powdery mildew**
  - White powder can be seen on the upper side of the leaves and stems
  - Powdery mildew affects the overall plant growth resulting in stunted plant growth, leaf

drop, and yellowing of plant tissue. In severe cases it can kill the plants

- Moderate temperatures (15 to 26 °C) with relative humidity above 50% and shady conditions are favorable for powdery mildew incidence. But it does not occur when leaf surface is wet
- The infection rate increases with rise in relative humidity above 90%

- **Downy mildew**

  - Downy mildew mostly appears on the underside of leaves
  - It causes yellowing of leaves
  - Prolonged wet condition in the hydroponics system or when leaves have been wet for long-duration, it favors the incidence of downy mildew
  - The optimum temperature for downy mildew is 18 °C
  - The disease becomes severe in cool and humid conditions (relative humidity 85%) so it is critical to maintain the relative humidity below 85%

- **Gray mold**

  - Also called ash mold & ghost spot
  - It appears as small spots on leaves and fruits that develop into fuzzy gray abrasions. It will further deteriorate until the plants are brown and mushy
  - Gray mold infection occurs at relative humidity above 93% with temperature (16-24 °C)

- **Late blight**

  - A major disease of potato and tomato
  - The disease occurs in humid or damp conditions with temperatures ranging between 16 and 21 °C
  - If not timely controlled, it will spread rapidly to other healthy plants destroying all plants in the system
  - Choose blight resistant varieties
  - Prolonged hot dry conditions in the growing area can control the disease spread

3.6.Common disease management practices

- **Wear clean clothes**
  - Disease inoculums or spores can enter into hydroponics system along with people entering the growing area so the clothes and shoes that are worn by the workers or people visiting the system should to be clean when entering the system
  - Keep the system and growing area clean at all times and especially while working inside it
- **Clean up spills and runoff**

  Water used in the hydroponics system can be one main source of disease inoculums as most of the plant diseases (gray mold, mildews, and other diseases) occurring in the hydroponics system is due to excess moisture/humidity. So, it is important to regulate or check the water use
- **Keep plants clean**

  Dried leaves and dead plant matter should be picked and thrown out of the hydroponics system. Do not keep any dead plant matter in the system as they harbor diseases and pests. The less dead plant matters the fewer pests and diseases

- **Use of fungicides**

  - Fungicides can be used as the last measure to control diseases

- Captan 50 WP (2gm/L) can control gray mold, powdery mildew and root rot (root treatment)
- Copper oxychloride 50 WP (1ml/L), metalaxyl 8% + mancozeb 64% (2gm/L) and mancozeb 75 WP (2gm/L) can control downy mildew and blight diseases of potatoes and tomatoes
- Sulphur 80 WP can control powdery mildew

3.7.Common weeds in hydroponics system

- **Algae/algal bloom**
  - Algae/algal blooms are thick layers of free-floating aquatic plants. Can be green, red, black, and brown in color
  - Algae incidence in hydroponics system is unavoidable to certain extent because algae require the same conditions (light, nutrients and water) as edible plants for their growth
  - Can be transported as microscopic spores through the air
  - Algae bloom in small amounts is not problematic but in huge masses, it can clog the pipes leading to overflow or block the pump causing the system to stop working. It can also compete with plants for nutrients and oxygen

3.8.Common weed management practices

- Prevent the light from reaching the nutrient solution with the use of opaque and black colored materials. This will reduce the photosynthesis rate of algae thereby controlling the algae growth
- Grapefruit seed extract (5 to 10 drops per 3.8 liters of water) is sufficient to prevent the algae growth without being toxic to plants
- Thoroughly clean the hydroponics system with food grade 35% hydrogen peroxide (3 milliliters for 3.8 liters of water) or clean water after h

SESSION-4 (2 Days Programs)

(Trainers: Dorji Wangmo & Karma Yangzom,ARDC Wengkhar)

4. PROTECTED HYDROPONICS STRUCTURES

4.1.Protected structures for hydroponics cultivation technology

Protected hydroponics structure involves growing crops in a controlled environment wherein parameters like temperature, humidity, light, water, plant nutrition etc., are controlled unlike in open field conditions where the crops are exposed to the fluctuations of nature. Various types of protected structures are available as per area, location, and choice of crops. Commonly used protected structures like greenhouse, with little modifications can be used for hydroponics system. Specialized structures required for hydroponics are stand, piping system; grow bags, troughs, containers, pot stands and chambers and can be made or constructed inside protected structures with additional investment. Cooling pad, exhaust fan, ceiling fan and electric heaters are required to control micro-climate for protected structures.

4.2. Greenhouse

- A greenhouse is a framed or an inflated structure covered with transparent or translucent materials such as PVC sheet, plastic sheets, glass that retains heat (*Figure 18*).
- Based on its transparency the greenhouse transmits most of the sunlight energy

Figure 18. Greenhouse

- The crop, floor and other objects inside the greenhouse absorb the sunlight and convert into infrared ray and heat energy which will increase temperature inside the greenhouse.
- The light energy converted into infrared rays cannot pass through greenhouse. This is known as greenhouse effect
- The green house effect(*figure 19*) creates ambient conditions for year round cultivation of crops.

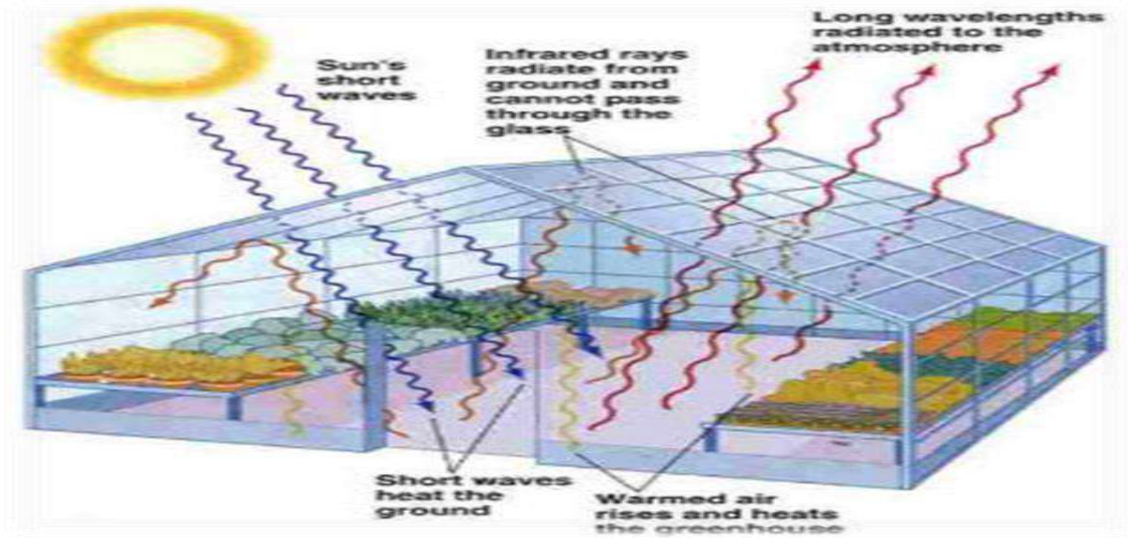


Figure 19. Principle of greenhouse effect

4.2.1. Prefabricated Greenhouse for hydroponics

Prefabricated green houses are structures commercially available with complete sets in ready to use form (*figure 20*).

Figure 20. Prefabricated Greenhouse for hydroponics

4.2.2. Fabricated greenhouse for hydroponics

Fabricated green house (*figure 21*) is a modified structure constructed using readily available materials such as bamboo, GI pipe, wood, rope, etc. It is classified into low and medium cost.

Figure 21. Low cost and medium cost fabricated greenhouses

Table 8. Material required for fabricated greenhouse (Size: 20mX5m)

Low cost				Medium cost			
Materials	**Estimated Quantity**	**Unit**	**Estimated Cost (in Nu.)**	**Materials**	**Estimated Quantity**	**Unit**	**Estimated Cost (in Nu.)**
200-micron polyethylene sheet	1	No	20000.00	Green house set	1	Set	85500.00
Bamboo	100	No	12000.00	25 mm GI pipe	50	m	10000.00
GI binding wire	2	Roll	4000.00	Cement(50kg)	45	Bag	23000.00
Jute bag (50 kg)	50	No	5000.00	Gravels	315	CFT	11025.00
Agro net	1	No	4500.00	Sand	160	CFT	2400.00
AC Exhaust fan (900 rpm, 450 mm sweep)	2	No	6000.00	Boulders	10	Tonne	18000.00
Ceiling Fan (1400 rpm, 1400 mm sweep)	2	No	2500.00	AC Exhaust fan (900 rpm, 450 mm sweep)	2	No	6000.00
Ventilation/Insect proof net	50	M	6000.00	Agro net	1	No	4500.00
Miscellaneous items	Lumpsum		10000.00	Miscellaneous	Lumpsum		10000.00
Total			**70600.00**				**168025.00**

- **General tools for greenhouse construction**

  Tools and equipment like angle cutter, pliers, hammer, measuring tape, ladder, crowbar, spade, shovel, electric drill, welding machine

4.3.Construction of different hydroponic techniques

4.3.1. Nutrient Film Technique (NFT)

NFT structure can be constructed using readily available commercial materials in the local market such as PVC pipes, GI pipes, and CPVC pipes or directly procure ready to use complete set.

Figure 22. Modified NFT materials

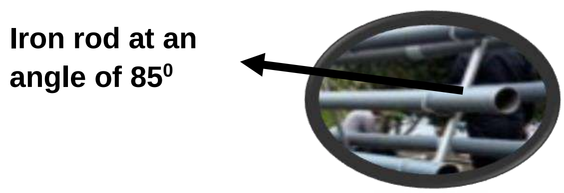
Figure 23. Ready to use NFT materials

Table 9. Materials required for Fabricated NFT

Materials required for 20mx5m greenhouse	Estimated Quantity	Unit	Estimated Cost (in Nu.)
PVC pipe (110mm diameter,3m length)	200	No	390000.00
PVC Socket(110mm)	40	No	6000.00
PVC end cap	65	No	9800.00
CPVC Pipe (32mm)	10	No	10000.00
CPVC pipe (20mm)	8	No	4500.00
CPVC elbow(32mm)	80	No	5500.00
CPVC elbow (20mm)	10	No	500.00
CPVC ball valve(32mm)	5	No	5000.00
CPVC ball valve (20mm)	5	No	3000.00
MS tubular for A-frame (50mm diameter)	160	M	70000.00
Iron rod (12mm)	100	M	4000.00
Nutrient Pump	1	No	9000.00
Nutrient tank (sintex 3000L)	1	No	25000.00
Total			**460000.00**

Steps to construct fabricated NFT

- Erect the iron rod in A-frame shape
- Weld the 0.2 m long, 15 mm metal rod to the iron rod at an angle of 85º with the use of welding machine
- Join the PVC pipes with its union till the required length
- Make planting holes to the PVC pipes using hole saw drill bit
- Fix the PVC pipes to the welded metal rod
- Connect the CPVC pipes for nutrient solution inlet and outlet to the nutrient reservoir tank and the growth chamber



4.3.2. Deep Water Culture (DWC)

DWC is a structure constructed using readily available materials such as concreting materials, buckets, wooden box, silpaulin sheet, PVC pipes, CPVC, pipes, styrofoam, etc. (*figure 24).*

Figure 22. Deep Water Culture (DWC)

Table 10. Materials for construction of DWC (Concrete type)

Materials required for 20mx5m greenhouse	Estimated Quantity	Unit	Estimated Cost (in Nu.)
Bricks (190*90*90mm)	2500	No	62500.00
silpaulin (300 gsm)	90	M2	18000.00
styrofoam	54	M2	25000.00
Netted pot	5400	No	110000.00
cements (50 kg bag)	6	Bag	3000.00
Sand	32	Bag	500.00
Total			**218500.00**

Steps to construct DWC

- Layout- measure 18mx1m planting trough size x 3 rows, maintain 50 cm space between the rows for intercultural operations
- Align one layer of bricks on the outline and stack the remaining layers of bricks till the structure meets height of 20cm
- Cure the structure for minimum of 2-3 weeks

Figure 23. DWC Structure

- Spread the silpaulin sheet over the planting trough as per trough size
- Fill in the nutrient solution
- Place the styrofoam over the nutrient solution [drill holes (10cmx10cm spacing) using hole saw drill bit in the styrofoam prior to filling up the structure with nutrient solution.

4.3.3. Drip System

4.3.3.1. Trough method

A structure constructed using the readily available materials such as planks, silpaulin sheet and is recommended for larger crops like tomatoes, chilli, cucumber, etc. as shown in *figure 26.*

Figure 24. Trough method structure

Table 11. Materials required for fabricated drip (Trough method)

Materials required for 20mx5m greenhouse	Estimated Quantity	Unit	Estimated Cost (in Nu.)
Planks for constructing planting trough (0.08ft thickness, 12 ft length, 1ft height)	80	CFT	31500
Silpaulin (300gsm)	90	M^2	18000
Drip Set	1	Set	7500
Case N capping	155	M	8000
HDPE Pipe(25mm)	50	M	3000
CPVC Ball Valve (25mm) (only one required if automated)	3	No	1800.00
CPVC Ball valve (32mm)	1	No	1000.00
Solenoid Valve	1	No	5000.00
CPVC pipe(25mm)	6	M	5400.00
Screen Filter (12meter cube per hr)	1	No	5000.00
CPVC Female Threaded adapter (FTA)(40m)	2	No	150.00
CPVC reducer bush(40*25mm)	2	No	150.00
Total			**86500.00**

How to construct Drip system (Trough method)

- Layout- measure 18mx0.5m planting trough size x 4 rows, maintain 50 cm space between the rows for intercultural operations
- Construct the trough using planks of recommended size
- Spread the silpaulin sheet over the planting trough as per trough size
- Put in the growing media of your choice (Moss +coco peat mixture 2:1/coco peat/moss)
- Install the drip irrigation set
- Install the nutrient distribution network

4.3.3.2.Pot method

A structure constructed using the readily available materials such as pots, buckets, containers, etc. and is recommended for crop like strawberry, herbs, leafy greens, etc. as shown in *figure 27.*

Figure 25. Pot method structure

Table 12. Materials required for fabricated drip system (Pot method)

Materials required for 20mx5m greenhouse	Estimated Quantity	Unit	Estimated Cost (in Nu.)
HDPE Pipe(20mm)	1	Roll	4000.00
Pots	150	No	15000.00
HDPE extension Pipe (6mm Outer diameter)	300	M	4500.00
Drip emitter (2.2 Litre Per Hour)	300	No	1500.00
Screw takes off (6mm, 1 end barbed hook)	300	No	2000.00
Nutrient Tank (Sintex tank,200L)	1	No	4000.00
CPVC Ball Valve (25mm) (only one required if automated)	3	No	1800.00
CPVC Ball valve (32mm)	1	No	1000.00
Solenoid Valve	1	No	5000.00
CPVC pipe(25mm)	6	M	5400.00
Screen Filter (12meter cube per hr)	1	No	5000.00
CPVC Female Threaded adapter (FTA)(40mm)	2	No	150.00
CPVC reducer bush(40*25mm)	2	No	150.00
Total			**49500.00**

Steps to construct Drip system (Pot method)

- Layout - Measure 18mx1mx 3 rows (each row consists of two lines)
- Place 40 numbers of pots in each line and 80 numbers in each row
- Put in the growing media of your choice (coco peat and moss mixture, vermiculite and soilrite mixture 2:1)
- Install the drip irrigation lines to each pot
- Install the nutrient distribution network

4.3.4. Sprinkler based vertical tower system

The structure is a modified aeroponic technique where the plants are grown in vertical PVC pipes. Nutrient solutions are provided through micro-sprinkler fixed above the tower. Compared to other techniques, this structure accommodates more number of plants per unit area. The structure is shown in *figure 28.*

Figure 26. Sprinkler based vertical tower system

Table 13. Materials required for sprinkler vertical tower system

Materials required for 20mx5m greenhouse	Estimated Quantity	Unit	Estimated Cost (Nu.)
PVC pipes (110mm)	150	No	292500
PVC TEE (110mm)	140	No	44500
PVC Elbow (110mm)	20	No	3000.00
PVC Socket(110mm)	186	No	99500
Micro sprinkler	130	No	6500.00
CPVC pipe(20mm)	36	No	1800.00
CPVC TEE (20mm)	150	No	7500.00
CPVC Elbow (20mm)	50	No	2500.00
CPVC socket (20mm)	50	No	2500.00
0.5 hp pump	3	No	8500.00
CPVC ball valve (32mm)	5	No	5000.00
CPVC tank nipple(20mm)	10	No	3500.00
Total			**436500**

Steps to construct sprinkler based vertical tower system

- Cut the PVC pipes into required length of the tower (2m)
- Mould planting holes in the PVC pipes with the use of heat gun (36 numbers)
- Fit the tower into the PVC TEE and elbow

- Install the nutrient circulation network
- Install the nutrient pump
- Automate the pump

Table 14. Materials required for vertical hydroponics tower

Materials required in 20mx5m green house	Estimated quantity	Unit	Estimated cost (in Nu.)
Planks for constructing planting trough (0.08ft thickness,12 ft length, 1ft height)	80	CFT	31500.00
Silpaulin (300gsm)	90	M^2	18000.00
Case N capping	155	M	8000.00
CPVC Pipe(32mm)	15	No	15000.00
CPVC Pipe (20mm)	10	No	6000.00
Auto-siphon valve(50mm)	4	No	20000.00
AC Pump (1 hp)	1	No	9500.00
CPVC TEE (20mm)	10	No	1500.00
CPVC Elbow(20mm)	10	No	500.00
CPVC TEE (32mm)	10	No	3500.00
CPVC Elbow (32mm)	10	No	1500.00
Total			**115000.00**

4.3.5. Ebb and flow (flood and drain)

This technique of hydroponics system is also known as flood and drains system and is constructed using readily available materials in the local market such as planks, silpaulin, PVC pipes and CPVC pipes. It is shown in *figure 29.*

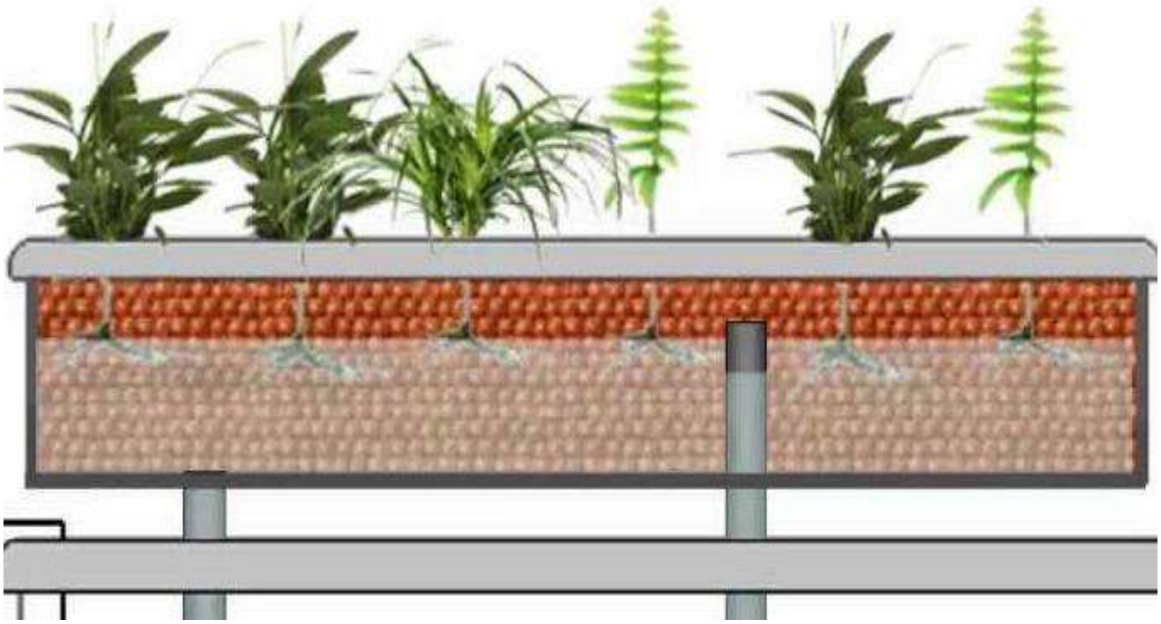


Figure 27. Ebb and flow

Table 15. Materials required for Ebb and flow technique

Materials required in 20mx5m green house	Estimated quantity	Unit	Estimated cost (in Nu.)
Planks for constructing planting **trough (**0.08ft thickness,12 ft length, 1ft height)	80	CFT	31500.00
Silpaulin (300gsm)	90	M^2	18000.00
Case N capping	155	M	8000.00
CPVC Pipe(32mm)	15	No	15000.00
CPVC Pipe (20mm)	10	No	6000.00
Auto-siphon valve(50mm)	4	No	20000.00
AC Pump (1 hp)	1	No	9500.00
CPVC TEE(20mm)	10	No	1500.00
CPVC Elbow(20mm)	10	No	500.00
CPVC TEE (32mm)	10	No	3500.00
CPVC Elbow (32mm)	10	No	1500.00
Total			**115000.00**

Steps to construct EBB AND FLOW (Type-flood and drain)

- Layout- measure 18mx0.5m planting trough size x 4 rows, maintain 50 cm space between the rows for intercultural operations
- Construct the trough using planks of recommended size
- Install the inlet and outlet pipe and fix it to the nutrient reservoir tank
- Spread the silpaulin sheet over the planting trough as per trough size
- Put in the growing media of your choice (Moss +coco peat mixture 2:1/coco peat/moss)
- Install an auto siphon to each planting trough

4.4.General tools/equipment required

Table 16. General tools/equipment required

NFT	DFT	DRIP	Vertical tower	EBB and flow
Measuring tape, welding machine, hole saw drill bit, drill machine, saw/hexo blade with frame, CPVC pipe cutter and GI pipe	Hole saw drill bit, brick trowel, concrete finishing trowel, pipe cutter Plumbing tools	Measuring tape, Pipe cutter, Plumbing tools, Drill machine with drill bits	Measuring tape, Pipe cutter, Plumbing tools, Drill machine with drill bits	Measuring tape, Pipe cutter, Plumbing tools Drill machine with drill bits

4.5.Maintenance of hydroponics structure

- The hydroponics system, tools and equipment should be completely sanitized at the end of each crop cycle
- Sterilize the system, tools and equipment using bleach, hydrogen peroxide, and antibacterial products like lysol. These can be applied in sprays, dunks, or soaks.

SESSION-5 (1 Day Program)

(Trainers: Dr.Tshering Penjor, ARDC Wengkhar & Kinley Tshering, ARDC Bajo)

5. AUTOMATION OF PROTECTED CULTIVATION TECHNOLOGY

5.1.Why we need automation in the hydroponics?

In the hydroponics system there are several parameters such as air temperature and humidity, lights, water temperature, nutrient EC and pH which are difficult to be controlled or maintained precisely by human intervention. These parameters are important for a healthy and faster plant growth in hydroponics system. Therefore, automation devices are necessary to maintain these parameters within optimum level to provide ambient conditions for plant growth.

One of the biggest recurring costs for any hydroponics system is labor. Automation of hydroponics system can reduce labor required for crop production and reduce labor cost. Aside from reducing labor cost, the automation also improves the efficiency in usage of other inputs such as plant nutrient, water and electricity which further reduces the recurring cost for operation of hydroponics system.

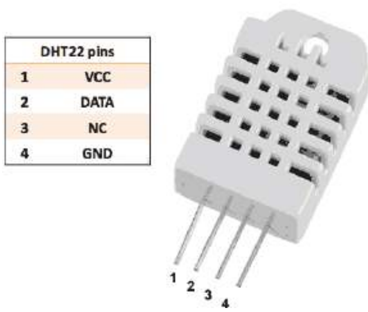
5.2.Devices and equipment used in hydroponics automation

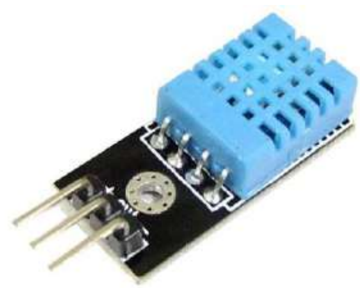
There are number of different integrated electronic devices or modules used in the hydroponics system and are categorized under the following groups based on their specific functions:

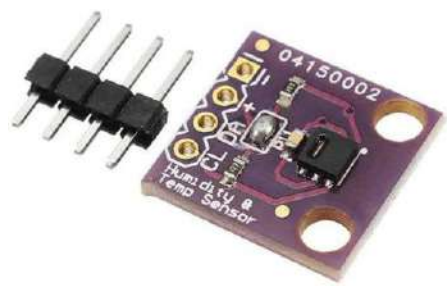
5.2.1. Sensor

Sensor is an electronic device or module that detect events or changes in its environment and send the information to the hydroponics controller. The readings from these sensors are used for activation or deactivation of different actuators (electric devices) to maintain the preset conditions in the hydroponics system. The readings from these sensors are also displayed on a dashboard for monitoring as well as archiving for further analysis and storage. Different types of sensors used in hydroponics are:

- **Temperature and humidity sensor module***:* It is either an analog or digital sensor to detect changes of temperature and humidity inside the hydroponics structure. The readings from these sensors are used for activation of actuators such as heater, exhaust fan, humidifier and de-humidifier to maintain the preset temperature and humidity inside the hydroponics structure.







DHT22 module	DHT11 module	HTU21D module
Temperature range: -40-80℃	Temperature range: -40-80℃	Temperature range: -40-80℃
Accuracy: ±0.5℃	Accuracy: ±0.5℃	Accuracy: ±0.5℃
Humidity range: 0-100 %RH	Humidity range: 0-100 %RH	Humidity range: 0-100 %RH
Accuracy: ±2%RH	Accuracy: ±2%RH	Accuracy: ±2%RH

Figure 30. Examples of temperature and humidity sensor modules

- **Water temperature sensor:** It is either an analog or digital sensor that detect changes of water (nutrient solution) temperature in hydroponics structure.

DS18B20 digital water temperature Sensor

Range: -55 to 125°C (-67°F to +257°F)

Accuracy: ±0.5°C

109SS analog water temperature sensor

Range: -40° to +70°C

Accuracy: ±0.49°C

Figure 31: Examples of water temperature sensors

- **pH sensor probe:** It is either an analog or digital sensor that detect changes in pH of hydroponics nutrient solution. It measures the molar concentration of hydrogen ions (H+) that is present in the solution. The more hydrogen ions present in the solvent, more acidic is the solution. A pH level of 7.0 at 25°C is said to be neutral, a pH below 7.0 are considered acidic and a pH higher than 7.0 are basic. It is important to monitor pH level of nutrient solution as availability of different nutrients to the plants are affected by different levels of pH in the solution.

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TPX00016 analog pH Sensor probe	AnyLeaf digital pH sensor probe
pH Range: 0 – 14	pH Range: 0 – 14
pH Accuracy: 0.01	pH Accuracy: 0.01

Figure 32. Examples of pH sensor probe

- **EC (electrical conductivity)/ TDS (total dissolved solids) probe*:*** An EC probe measures the potential for an electrical current to be transported through water known as molar conductivity (electrolytic conductivity) and is measured in micro-Siemens per centimeter (µS/cm). When hydroponics nutrient is added to the water, it increases the molar conductivity potential for current through water and increases the EC value. The hydroponics nutrient dissolved in the water are all ions, EC can also be used as an indirect measurement of TDS. Therefore, EC /TDS probe are used to measure the concentration of hydroponics nutrient solutions.

Range: 0.07-50000 µS/cm

Accuracy: +/- 2 %. With TDS readings in ppm

Figure 33. EC and TDS probe

- **Carbon dioxide (CO_2) sensor module:** The CO_2 sensor module are used to monitor the level of CO_2 concentration in the hydroponics system. For the majority of **hydroponics crops**, net photosynthesis increases as CO_2 levels increase from 340–1,000 ppm.

Example:

Example: CO_2 Device and sensor module

- Range: 0 – 5,000 ppm
- Accuracy: ± 50 ppm

Figure 34. CO2 sensor module

- **Light sensor module:** Light sensor detects the ideal lighting conditions of the plants in the hydroponics system. It detects the brightness and intensity of light and controls the activation or de-activation of artificial lighting system in the hydroponics structure.

Example of light sensor module:

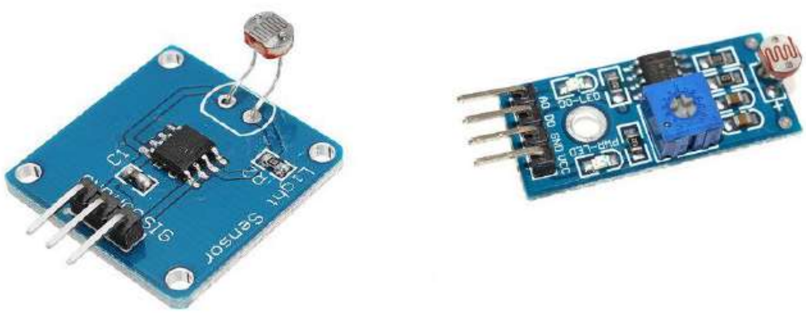


Figure 35. Examples of light sensor module

- **Water level sensor:** The water level sensor is used for determining nutrient level in the hydroponics nutrient tank. The sensor helps to maintain required water level in the nutrient reservoir.

  Example: Float magnetic switch

Figure 36. Water level sensor

- **Moisture sensor module*:*** Moisture sensors detect and monitor the moisture level of plant root zones especially in the substrate-based hydroponics system. The data from these sensors are sent to the hydroponics controller to activate or deactivate the solenoid valve or nutrient pump for nutrient circulation based on the pre-set conditions.

Figure 37. Capacitive moisture sensor module

5.2.2. Actuators

An actuator is either a device or an application software that is operated or activated based on the sensor values that is pre-set in the hydroponics controller device. Actuators used in hydroponics system are:

- **Nutrient pump:** Nutrient pump is an electric pump which is used for circulation of the nutrient solution from the reservoir tank to the growth chamber in the hydroponics system. In aeroponics and NFT systems, frequent switching ON and OFF of the nutrient pump is required to supply nutrients and moisture to the root zone of the plants. Alternating current (AC) and direct current (DC) powered electric pump can be used in the hydroponics system. Power rating of the pumps depend on the size of the hydroponics structure. Two types of nutrient pumps are available, submersible and non-submersible pumps.

0.5 HP Submersible AC pump

0.5 HP none-submersible AC pump

Figure 38. Examples of nutrient pump

- **Air pump:** It is used to pump air bubbles into the nutrient tank to increase the oxygen level in the nutrient solution. In DWC system, air pumps are necessary to oxygenate the roots of the plants. It is available in various sizes having one or two air outlets.

  Example: DC powered air pump

Figure 39. Air pump

- **Peristaltic pump:** It is commonly known as a roller pump and it is used for pumping a variety of fluids in a very accurate discharge rate. The peristaltic pumps are used to dispense accurate volume of concentrated nutrient solutions and pH adjusting solutions to the hydroponics nutrient reservoir and maintains EC and pH levels at the pre-set values automatically.

Example: Peristaltic dosing pump

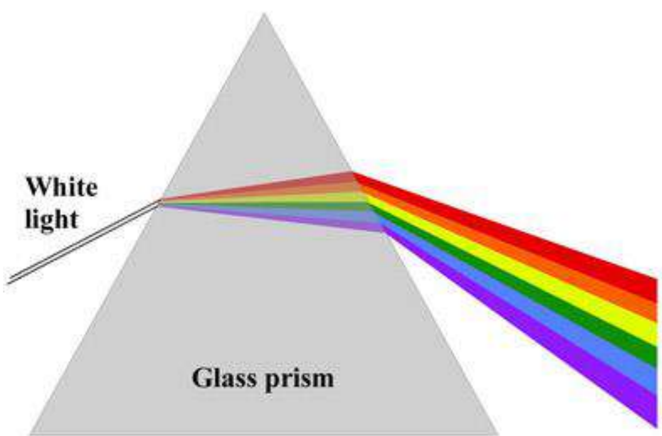
Figure 40. Peristaltic pump

- **Solenoid valve:** It is an electrically controlled valve to turn ON or OFF to regulate the flow of nutrient solution. It automatically controls the distribution network of nutrient and water circulation.

Figure 41. Solenoid pump

- ***Hydroponics electric heater:*** In hydroponics, most of the heaters are electric-powered used for providing heat during winter months. The submersible type of electric heaters is also used to heat up the nutrient solutions in the reservoir tanks to maintain the required temperature level.

- ***Grow-lights***: All green plants require light as a source of energy for photosynthesis. For indoor hydroponics system, the artificial lighting system is necessary as plants have no access to the sunlight. For out-door hydroponics system, artificial lighting may be provided if the light from the sun is not enough for proper plant development. Most plants use about 495 – 570 nm (Nano meter) range of visible light spectrum, where the green parts of spectrum are reflected by chlorophyll. During the vegetative stage, plants require more of blue spectrum of light which has higher energy content. During flowering and fruiting (reproductive) stage, the plants require more of red spectrum light which is low energy part of the light spectrum.



Color	λ (nm)	Freq (Hz)
Red	760-647	$4.3x10^{14}$
Orange	647-585	$4.3x10^{14}$
Yellow	585-575	$5.2x10^{14}$
Green	575-491	$5.6x10^{14}$
Blue	491-424	$6.6x10^{14}$
Violet	424-380	$7.3x10^{14}$

Figure 42. Grow light

- **Lighting system**

    - ***Timer based lighting***: Timer device turns lights ON or OFF based on the time set in the device

- *Conditional lighting*: Controller device determines when to turnthe lights ON or OFF based on the conditions set in the controller device.

- **Types of grow light:**

  - **Fluorescent tube:** Florescent tube can be used for lighting in the hydroponics system as they are cheap, readily available in the local market and provide full spectrum (white light) of light for the plants.

Figure 43. Fluorescent tube

  - **Compact Fluorescent bulbs**
  - ***(CFL)***: CFL light can be used as they are cheap, easy to use and readily available. CFL bulbs are available in different power ratings and sizes and provides full spectrum light for the plants.

Figure 44. Compact fluorescent bulbs

- **LED (Light Emitting Diode) lights:** LED grow lights are considered to be the most efficient lighting system in the hydroponics system. They produce combination of blue and red light as required by the plants. LED grow lights are more energy efficient compared to other lighting sources and if properly maintained it will last for 5 to 10 years.

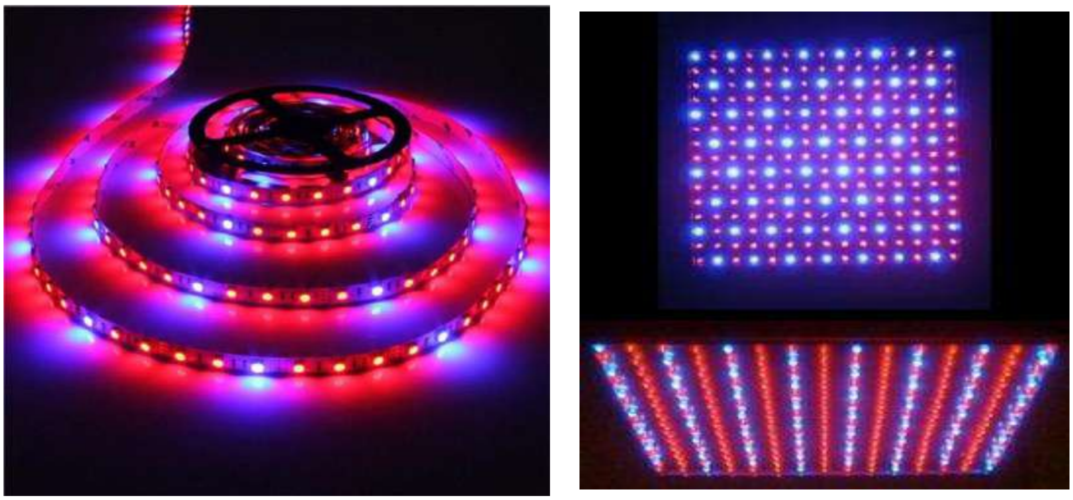


Figure 45. LED grow light

- **Electric fans*:*** It is generally used for ventilating and cooling the hydroponics structure. The most critical electric fan used in the hydroponics system is exhaust fan for removing accumulated heat and moisture (humidity) from the growth chamber.

Figure 46. Electric fan

- **Webcam:** Webcam or any other camera are used to take time-lapse or real time pictures for monitoring the hydroponics system.

Figure 47. Webcam

5.2.3. Hydroponics controlling Device

The main function of the hydroponics controlling device is to acquire readings from different sensors, analyze data and control pre-set parameters with the help of different actuators present in the system. Remote monitoring is also one of the main functions of the hydroponics controlling device. There are various hydroponics automation devices available in the market and are categorized into two types:

- **Traditional stand-alone controller:** It has no access to internet facilities and cannot be monitored remotely.
- **Internet based controller:** It has access to internet facilities and can be monitored and controlled through secure mobile apps, web or other IoTs (Internet of Things) facilities.

5.2.4. Configuration of Locally developed hydroponics controlling device:

Although various types of hydroponics controllers are available in the market but many are expensive and lack local technical expertise for installation, usage and maintenance of these devices. Established hydroponics structures in research centers use hydroponics controllers developed by local private IT firm in Bhutan. The section below describes how to use and configure both hardware and software.

5.2.4.1.Hardware components:

The system uses open-source hardware such as raspberry Pi, ESP8266 and ESP32 microcontrollers with Wi-Fi and internet capability. The hardware has a number of input and output ports to interface with a number of sensors and actuators to control different parameters in hydroponics system.

Input ports for different sensors:

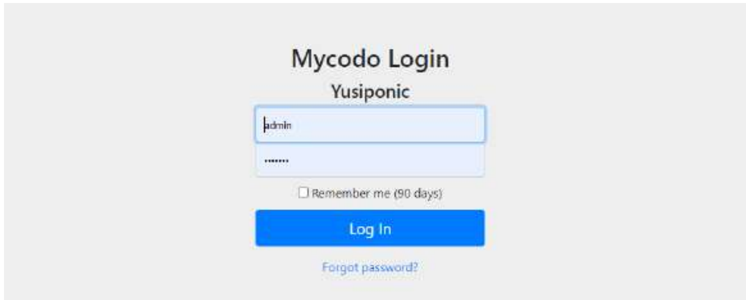
- Temperature and Humidity sensor
- Water temperature sensor
- Water level sensor
- pH sensor
- EC sensor

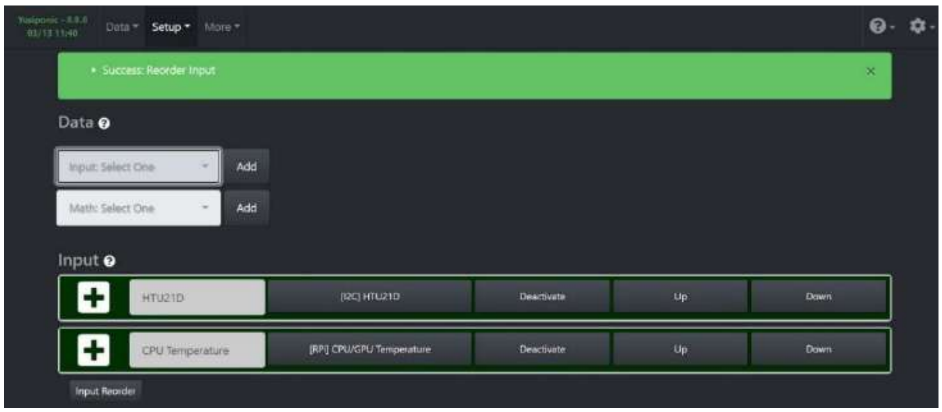
Output ports for different actuators:

- Nutrient pump
- Air pump
- Grow lights
- Exhaust fan
- Heaters
- Ceiling fan
- Solenoid valve

5.2.4.2.Application Software configuration:

The software on the hydroponics controller is called Mycodo which can be accessed using any web browser apps such as Google Chrome, Microsoft Internet Explorer and Firefox by using the device IP address. The device can also be accessed worldwide using other cloud based IoT services such as *Dataplicity.com*. The application software is secure and protected by login credentials. The default login is *admin* and password are *default.* After the login, configure different sensors and actuators.





In the Mycodo software, the automation of hydroponics system is achieved by interaction of various sensors and actuators under the FUNCTION setting in the software. Navigate to the **Setup -> Function** page, where several functions will be created that will automate the system. For example

- Timer to turn ON or OFF for grow light, nutrient and oxygen pumps
- Function to regulate EC and pH with the peristaltic pump.
- Function to regulate room temperature with a humidifier and exhaust fan.
- Function to monitor air and water temperature, water level, or other important measurements and alert by email if they fall out of acceptable range.
- Timer to periodically run exhaust fan.

- **Dashboard for real-time monitoring the status of different sensors and actuators**

On the **Data -> Dashboard** page, there are many types of widgets that can be added, organized by dragging and resizing. The most useful widget is the graphs which allows to select any number of Inputs, Outputs, controllers, and other measurements to be displayed on a historical graph. Graphs are updated automatically with new data and displays the latest measurements. There are also a number of settings to tune the graph including the x-axis duration, series colors, and range selector etc, Multiple dashboards created to organize different views, or to prevent one dashboard from becoming too crowded.

Annexure 1. **Training schedule**

Session 1: Principles and concepts of hydroponics system

Day/Time	Activity	Mode of Training	Responsibility
Day 1			
8:45-9.00AM	Participant's registration		Training coordinator, ARDC Bajo
9:00-10.30 AM	Introduction to the training program (Principles and concepts of hydroponics system)	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Tea break (10.30-11.00AM)			
11:00-1.00PM	Why hydroponics and its challenges and opportunities	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Lunch break (1.00-2.00PM)			
2:00-4.00PM	Basic principles of hydroponics and requirement for crop growth	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Tea break (3.30-4.00PM)			
4.00-5.00PM	Suitable crops for hydroponics and its companion crops	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Day 2			
8:45-9.00AM	Participant's registration		Training coordinator, ARDC Bajo
9:00-10.30 AM	Types of hydroponic systems (substrate based, hydroponics)	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Tea break (10.30-11.00AM)			
11:00-1.00PM	Types of hydroponic systems (Aeroponics, Fogponics)	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Lunch break (1.00-2.00PM)			
2:00-3.30PM	Demonstration on different types of Hydroponic system	Practical	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Tea break (3.30-4.00PM)			

4.00-5.00PM	Test on practical session	Theory	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Day 3			
8:45-9.00AM	Participant's registration		Training coordinator, ARDC Bajo
9:00-10.30 AM	Nursery raising and Transplanting techniques in hydroponics	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Tea break (10.30-11.00AM)			
11:00-1.00PM	Harvesting and management techniques in hydroponics	Lecture/ Presentation	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Lunch break (1.00-2.00PM)			
2:00-3.30PM	Practical on nursery raising, transplanting and harvesting	Practical	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang
Tea break (3.30-4.00PM)			
4.00-5.00PM	Practical on nursery raising, transplanting and harvesting	Practical	Kinlay Tshering, Tshering Dema,ARDC Bajo & Ugyen Wangmo,NCOA Yusipang

Session 2: Plant Nutrient Solutions

Day/Time	Activity	Mode of Training	Responsibility
Day 4			
8:45-9.00AM	Participant's registration		Training coordinator, ARDC Bajo
9:00-10.30 AM	Introduction to the training program (Plant Nutrient Solutions)	Lecture/ Presentation	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (10.30-11.00AM)			
11:00-1.00PM	Nutrient formulation and Premix followed by discussion(Q&A)	Lecture/ Presentation	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Lunch break (1.00-2.00PM)			
2:00-4.00PM	Practical on nutrient formulation	Practical	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (3.30-4.00PM)			
4.00-5.00PM	Test on practical session	Discussion	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha

Day 5			
8:45-9.00AM	Participant's registration		Training coordinator, ARDC Bajo
9:00-10.30 AM	Water quality, pH, EC and TDS	Lecture/ Presentation	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (10.30-11.00AM)			
11:00-1.00PM	pH and EC Calculate and Temperature followed by discussion(Q&A)	Lecture/ Presentation	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Lunch break (1.00-2.00PM)			
2:00-4.00PM	Practical on Premix preparation	Practical	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (3.30-4.00PM)			
4.00-5.00PM	Test on practical session	Theory	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Day 6			
8:45-9.00AM	Participant's registration		Training coordinator, ARDC Bajo
9:00-10.30 AM	Theory on reagent grade solution	Lecture/ Presentation	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (10.30-11.00AM)			
11:00-1.00PM	Practical on reagent grade solution	Practical	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Lunch break (1.00-2.00PM)			
2:00-3.30PM	Practical on nutrient formulation	Practical	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (3.30-4.00PM)			
4.00-5.00PM	Practical on nutrient formulation followed by discussion(Q&A)	Practical/ Theory	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Day 7			
8:45-9.00AM	Participant's registration		Training coordinator, ARDC Bajo
9:00-10.30 AM	Practical on organic based solution preparation	Practical	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (10.30-11.00AM)			
11:00-1.00PM	Continue practical on organic based solution preparation	Practical	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha

Lunch break (1.00-2.00PM)			
2:00-3.30PM	Discussion and recap on past 3 days training programs	Theory	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha
Tea break (3.30-4.00PM)			
4.00-5.00PM	Feedback & suggestion from trainee	Theory	Suraj Chettri & Tashi Wangchuk, NSSC, Semtokha

Session 3: Pest, Disease and Weed management

Day/Time	Activity	Mode of Training	Responsibility
Day 8			
8:45-9.00AM	Participant's registration		Training Coordinator, ARDC Bajo
9:00-9.20 AM	Introduction to the training program (Pest, disease and weed management)	Lecture/ Presentation	Pema Tshoki, NPPC, Semtokha
9:20-10.30 AM	Hydroponics- Insect pests and their management followed by discussion (Q&A)		
Tea break (10.30-11.00AM)			
11:00-12.00PM	Hydroponics diseases and their management followed by discussion(Q&A)	Lecture/ Presentation	Pema Tshoki, NPPC, Semtokha
12:00-1.00PM	Hydroponics weeds and their management followed by discussion(Q&A)		
Lunch break (1.00-2.00PM)			
2:00-3.30PM	Display of insect pests, sticky traps, preparation of dilute solution of pesticides/fungicides		Pema Tshoki, NPPC, Semtokha
Tea break (3.30-4.00PM)			
4:00-5.00PM	Visit to hydroponics system to show the participants real situation occurrence of pest, disease and weed in the	Practical	Pema Tshoki, NPPC, Semtokha and Thinley Choden, NCOA, Yusipang

	Theory on organic based solution followed by discussion(Q&A)		

Session 4: Protected Hydroponics Structures

Day/Time	**Activity**	**Mode of training**	**Responsibility**
Day 9			
8:45-9.00AM	Participant's registration		Training Coordinator, ARDC Bajo
9:00-9.15 AM	Introduction to the training program (Protected Hydroponics Structures)	Lecture/ Presentation	Dorji Wangmo, ARDC-Wengkhar
9:15-10:30AM	Protected structures for hydroponics cultivation technology followed by discussion (Q&A)		Karma Yangzom, ARDC-Wengkhar
Tea break (10.30-11.00AM)			
11:00-12.00PM	Construction of different hydroponics technique (NFT/DWC)	Lecture/ Presentation	Dorji Wangmo, ARDC-Wengkhar
12:00-1.00AM	Display of construction tools & equipment (Pictorial) followed by discussion (Q&A)		Dorji Wangmo/Karma Yangzom, ARDC-Wengkhar
Lunch break (1:00-2.00PM)			
2:00-3.30PM	Hands on practice in handling greenhouse tools & equipment	Practical	Dorji Wangmo/Karma Yangzom, ARDC-Wengkhar
Tea break (3.30-4.00PM)			
4.00-5:00	Hands on practice in handling greenhouse tools & equipment followed by discussion (Q&A)	Practical	Dorji Wangmo/Karma Yangzom, ARDC-Wengkhar
Day 10			
8:45-9.00AM	Participant's registration		Coordinator, ARDC Bajo

9:00-9.30AM	Recap of Day 9	Discussion	Dorji Wangmo & Karma Yangzom, ARDC-Wengkhar
9:30-10.30AM	Construction of different hydroponics technique [Drip (Trough method/Pot method)]	Lecture/ Presentation	Karma Yangzom, ARDC-Wengkhar
Tea break (10.30-11.00AM)			
10.30-11:00PM	Construction of different hydroponics technique (Sprinkler based vertical tower system / Ebb & flow technique)	Lecture/ Presentation	Dorji Wangmo, ARDC-Wengkhar
12:00-1.00PM	Hands on practice in handling tools & equipment and material used in construction of different hydroponics technique	Practical	Dorji Wangmo/Karma Yangzom, ARDC-Wengkhar and ARDC Bajo
Lunch break (1:00-2.00PM)			
2:00-2.20PM	Maintenance of hydroponics structure & different techniques	Lecture/ Presentation	Dorji Wangmo, ARDC-Wengkhar
2:20-3.30PM	Display of cleaning materials with hands on practice	Lecture/ Presentation	Dorji Wangmo/Karma Yangzom, ARDC-Wengkhar
Tea break (3.30-4.00PM)			
3:30-5.00PM	Visit to hydroponics green house to familiarize the participants with greenhouse structure & hydroponics techniques (NFT/Ebb &flow technique/Drip) followed by discussion(Q&A)	Practical	Dorji Wangmo/Karma Yangzom, ARDC-Wengkhar, ARDC Bajo

Session 5: Automation of protected cultivation technology

Day/Time	Activity	Mode of Training	Responsibility
Day 11			
8:45-9.00AM	Participant's registration		Training Coordinator, ARDC, Bajo
9:00-9.30PM	Introduction to the training program (Automation of protected cultivation technology)	Lecture/ Presentation	Dr. Tshering Penjor, ARDC, Wengkhar
9:30-10.30AM	Automation of protected cultivation technology (Devices & equipment used)		Dr. Tshering Penjor, ARDC, Wengkhar
Tea break (10.30-11.00AM)			
11.00-12:00AM	Automation of protected cultivation technology (Devices & equipment used) followed by Discussion (Q&A)	Lecture/ Presentation	Dr. Tshering Penjor, ARDC, Wengkhar
12.00-1.00PM	Display of device & equipment with hands on practice		Dr. Tshering Penjor, ARDC, Wengkhar/ Kinley Tshering, ARDC, Bajo
Lunch break (1:00-2.00PM)			
2:00-2.30PM	Configuration of locally developed hydroponics controlling device	Lecture/ Presentation	Dr. Tshering Penjor, ARDC, Wengkhar/ Kinley Tshering, ARDC, Bajo
2:30-3.30PM	Hands on practice of configuration of locally developed hydroponics controlling device		Dr. Tshering Penjor, ARDC, Wengkhar/ Kinley Tshering, ARDC, Bajo
Tea break (3.30-4.00PM)			
4.00-5.00PM	Visit to hydroponics green house to familiarize the participants with automation followed by discussion(Q&A)	Practical	Dr. Tshering Penjor, ARDC, Wengkhar/ Kinley Tshering, ARDC, Bajo

SESSION-6 (4 Days Program)

BUSINESS PLANNING, ENTERPRISE DEVELOPMENT AND MARKET LINKAGE

(National Service Program)

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