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Sustainable Solutions in Agriculture Production

Supervisors

Prof. FRANCO LOMBARDI

Prof. GIULIA BRUNO

Prof. PAOLO CHIABERT

Candidate

AHMAD HUSSEIN

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"When there is a will, there is a way," says Pauline Kael in a well-known quote. That is true, but he never said where the will comes from, not just from your inner self, but also from the people that surrounds and loves you.

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Summary

Crops of all kinds are very essential life source that ensures the survival of human lives. Thus, to get a high quality of the plantation we must consider all natural factors that affects negatively in both direct and indirect ways.

The agriculture business is dealing with a variety of issues, including market volatility and, of course, climate change. To make matters even more difficult, by 2050, approximately 80% of the world's population is expected to be living in cities [1]. The quantity of fertile areas available for agricultural production is diminishing day by day as a result of urbanization and industrial growth.

Traditional farm isn't enough to cover all the market demand due to increasing population and decrease in natural resources that helps crops growing. More than 80% of the world's usable land for growing crops is currently in use, and experts stated in 2015 that a third of the world's arable lands had been lost since 1975 [1], in terms of soil consumption, groundwater, and environmental pollution. It goes without saying that an alternate option is required. Could vertical farming be the answer?

Green houses which it's new agronomic technologies and could be developed to other types of plantations at the basis of human nutrition can now be produced soilless, within artificial environments that represent the new frontier for the agriculture of the future. Hydroponic and aeroponic crops in vertical greenhouses are already an experimentation phase in many countries and promise very high yields, high organoleptic quality, and nutritional capacity, and with very low waste.

Our goal is to end up with high level research with complete information about the sustainable agriculture that can serve any farmer and facilitate the plantation process in his work and allow him to take a right decision and action.

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Chapter 1

Introduction

1.1 Statement of the Problem

Plants are an essential source of life, but it is being changed over the times due to natural and personal factors. Most of the fields are invested for agricultural and industrial uses around the world. Thus, if these field are continuing to use in a bad way we will lose the value of that field, many diseases and illnesses are going to be spread all around. Therefore, primitive farming is a main problem that must be solved and treated well as soon as possible.

1.2 Hypothesis or Key Questions

What if an advanced plantation system is made available to maintain the yards, fields and improving productivity and environmental sustainability? Would be a great solution if that system was designed to maintain our world?

1.3 Proposed Solution

The solution is collecting information about plantation, to be studied and analyzed in order to find an alternative methods more effective and provide a higher production quality. It is advanced system so that it does its work perfectly on time from seeding to harvesting and where that farmer can manage his plantation field and benefit from all services which require less employees to operate. This techniques was proposed because of many studies to see which solution is the most beneficial and applicable in the world within the available capabilities.

1.4 Specific Objectives

The objective of this project is to have clean environment and field that can be more sustainable, and free of diseases and microbes caused by the indiscriminate use of chemicals substances that are being used directly for agricultural. To achieve this objective, this advanced research should be done to maintain the agricultural fields and benefit from the vast areas that are not used for anything mainly in Italy. It must be a fast, stable, reliable, and environmental process.

1.5 Relevance of this Work

The new advanced technology (vertical farm) project is very important because it solves a problem every single person may face which is the lack of information in agriculture and green house. The most important point in our studies is to use everything could be eco and environment friendly, such as solar power, and natural organic material. It uses solar power so that it doesn't pollute the air; if not using smart plantation system in a good way, the project will be solving a problem while starting another vital problem for example air pollution. So, it should be sustainable chain.

1.6 State-of-the-Art

Vertical farming is a reducing technique that has opened up new possibilities for urban farming in the countryside. The study's goal, a sincere commitment to urban smart vertical farming and the use of technology, has created a new way of thinking about agriculture. In this period of technology, new technologies might help the agriculture business grow even more.

Chapter 2

Litreture Review

Although vertical farms have just recently emerged on the agricultural landscape, the principle behind these cutting-edge farming facilities is not new. Continue reading to learn about some of the historical theories, discoveries, innovations, and prototypes that have contributed to the current vertical farm's development.

2.1 A Look at the History of Vertical Farming

Pre-20th Century

The mythical Hanging Gardens of Babylon, erected by King Nebuchadnezzar II more than 2,500 years ago, are perhaps the first example of a "vertical farm." According to some experts, the gardens were made up of a succession of domed terraces that were built on top of each other and filled with a variety of plants and flowers. The gardens, which rise to a height of 20 meters, were most likely watered by a chain pump, which employed a system of buckets and pulleys to transport water from the Euphrates River at the bottom of the gardens to a pool at the top.

1150 A.D. The Aztecs employed "chinampas," a type of hydroponic farming, to produce vegetables in marshy places near lakes about a thousand years ago. Because the marshy terrain in these locations was unsuitable for cultivation, the Aztecs built rafts out of reeds, stalks, and roots, coated them with mud and dirt from the lakebed, and sailed them out into the lake. Crops may grow vertically with their roots growing downwards through the rafts and into the water because of the structural support given by the rafts. Often, a large number of these small rafts were connected to form large floating "fields."

In 1627, the book Sylva Sylvarum by English scientist and politician Sir Francis

Bacon contains the earliest documented theory of hydroponic gardening and agricultural technologies. Bacon establishes and investigates the potential of cultivating terrestrial plants without soil in this book.

In 1699, with a series of water culture experiments undertaken with spearmint, English scientist John Woodward refines the notion of hydroponic gardening. Woodward discovers that plants grow better in contaminated water than in pure water, leading him to believe that the plants get critical nutrients from soil and other additions added to water solutions [2].

20th Century and Beyond

Farmers have already established numerous methods of crop protection around the turn of the twentieth century. The field was first protected by erecting tiny boxes with a flat glass roof over the crops (1). Small-scale greenhouses were created during the next few years (2). These enclosures eventually became the first greenhouses as we know them today (3) as shown in the figure 2.1 [3].

Figure 2.1: Crop protection evolution.

The first drawing of a "modern" vertical farm appears in Life Magazine in 1909. The drawing depicts open-air layers of vertically stacked residences in a farmland setting, all of which are raising food for human consumption.

Gilbert Ellis Bailey, an American geologist, created the phrase "vertical farming" in his book of the same name in 1915. Bailey, interestingly, focuses on farming "down" rather than "above." That is, he investigates a sort of subterranean farming in which farmers utilize explosives to dig deeper into the ground, increasing their total usable area and allowing them to plant greater harvests.

Modern hydroponics is due to William F. Gericke, an agronomic at the University of California, Berkeley, who developed it in 1929. Gericke describes the technique of growing plants in sand, gravel, or liquid with additional nutrients but no soil in his essay "Aquaculture: A Means of Crop-production," published in December 1929.

In an article published in Science magazine in 1937, the term "hydroponics" is invented. The name "hydroponos" was offered to Gericke by his University of California collaborator, botanist William Albert Setchell, as an alternative to "aquaculture" (which was already in use to describe fish-breeding procedures).

For the first time in modern history, hydroponic farming systems are deployed on a big scale during World War II. To feed the Allied soldiers stationed in the South Pacific Islands, more than 8,000 tons of fresh vegetables are grown hydroponically.

A vertical farm in the shape of a tall glass tower is on show at the Vienna International Horticulture Exhibition in 1964.

In 1989 — Kenneth Yeang, an architect and environmentalist, envisioned mixed-use buildings that are harmoniously connected with green areas, allowing plant life to be cultivated in open-air structures. "Vegetated architecture," as Yeang put it. Unlike many other vertical farming concepts, this one focuses on personal and communal use rather than large-scale production and distribution.

Dr. Dickson Despommier, a Columbia University professor of environmental health sciences, develops the notion of the contemporary vertical farm in a seminar in 1999. Despommier and his students came up with the notion of a multi-story skyscraper with layers of crops cultivated on each floor, a modern vertical farming tower, in order to find out an effective way to feed New York's population using just urban rooftop agriculture. (Since then, Despommier has established himself as the world's leading specialist and proponent of vertical farming.)

In 2006, Nuvege, a Japanese startup, creates a proprietary light network that controls light outputs to boost the return rate of vegetables in indoor vertical farms.

The first contemporary vertical farm is constructed in 2009. The Sky Green Farms facility in Singapore is made up of over 100 9-meter-tall towers that use sunshine and rainfall to cultivate green vegetables [2].

2.2 Crops and its Categories

Crops are plants or plant-derived products that are produced and harvested for food or profit. Food crops, feed crops, fiber crops, oil crops, decorative crops, and industrial crops are the six main types of crops. Crops have become the major means of feeding humans in every corner of the earth since hunter-gatherer tribes transitioned to agricultural societies around 10,000 years ago during the Neolithic period. They still control not only food distribution and consumption, but also fuel, manufacturing, and almost every other business.

- Food Crops;

  Fruit and vegetables, as well as other food crops, are collected for human use. Grains, such as corn, wheat, and rice, are the most widely consumed foods on the planet. The earliest crops gathered through agriculture were food crops. Other varieties of crops arose as a result of agricultural progress and civilization advancement.

- Feed Crops;

  Animal feed crops, such as oats and alfalfa, are collected for consumption by cattle. These crops provide the nutrients that animals require to grow. They are produced in agricultural areas, but they may also be found in pastures and natural meadows.

  The importance of forage crops in livestock production cannot be overstated. Forages, such as grasses, are consumed directly by animals. Green chop refers to forages that are sliced and fed to animals when still fresh. Alfalfa is a common green chop crop for cattle. Some forages are harvested, dried in the field, and then stored. Hay crops are what they're called.

  Silage is another sort of fodder crop. Silage crops are collected and then kept in a way that allows the forage to ferment (break down) into acids. Cattle and other livestock are fed the moist, acidic silage.

  Corn, barley, wheat, and oats are the most common feed crops. Each of these crops has unique characteristics that make it better suitable for the diets of some animals than others. Because beef and dairy cattle have a tough, four-chambered stomach, barley, which is more difficult to digest, is commonly given to them. Swine and fowl are given hull-less barley, which is simpler to digest.

  With the rising demand for meat throughout the world, feed crop output has surged substantially. The agricultural landscape has transformed as a result of increased feed crop output. According to the Food and Agriculture Organization (FAO), animal feed accounts for 33 percent of all arable land on the planet. This reduces the amount of food that can be grown for human use, especially for the poorest people on the planet. Forests have been removed to make way for grazing meadows for animals. For example, grazing has taken up about 70% of the area removed from the Amazon rainforest.

- Fiber Crops;

  Textile and paper goods are made from fiber crops like cotton and hemp. Textiles, sometimes known as fabric, are manufactured from dried and processed plant fibers. The majority of textile fibers come from the stems or roots of plants like flax. Linen is made from flax.

  Fiber may be extracted from other components of a plant. Cotton is gathered from the light, fluffy "boll" of fiber that surrounds the plant's seeds, making it the world's most popular fiber crop. Bamboo textiles are created from the pulp of bamboo plants.

  Other fiber crops' pulp may be used to make a number of items. In the production of paper goods, fiber pulp can be used instead of wood pulp. The hemp plant is a fascinating and divisive example of a fiber crop. Hemp fibers are robust and resilient, making them ideal for items like paper, textiles, ropes, nets, and ship sailcloth. Hemp proponents perceive the plant as a flexible and environmentally friendly fabric source.

  However, certain hemp cultivars are used to generate marijuana, a psychoactive narcotic. In many places of the United States, it is unlawful to produce and consume marijuana. (In other regions, the substance is cultivated and marketed lawfully for medicinal or recreational purposes.) Opponents of hemp say that increasing hemp harvesting would lead to more marijuana production and consumption.

- Oil Crops;

  Canola and maize are two examples of oil crops that are harvested for human consumption or industrial purpose. Crops can now be processed and broken down into their essential components, including oil, thanks to technological advancements in the last century. In the year 2000, soybeans accounted for 61 percent of global oilseed output and 79 percent of all edible oil eaten in the United States.

  Olive oil and maize oil, for example, are collected for use in cooking. Oil crops are also gathered for industrial purposes including oil paints, soaps, and equipment lubrication.

  Bioethanol and biodiesel are the two most common biofuels made from oil crops. Bioethanol is an alcohol generated from sugar and starch crops that has been fermented. Sugar cane, maize, and wheat are among these crops.

Bioethanol can be used as a car fuel, although it's more commonly utilized as a gasoline addition to reduce emissions. Bioethanol is widely utilized in the United States and Brazil, where plentiful maize and sugar cane crops make production easier.

Vegetable oils and alcohol are combined to make biodiesel. Coconuts, macadamias, and pecans, for example, are great sources of oil for biodiesel production. In diesel engines, such as those used in buses, biodiesel can be used. Biodiesel is produced and used extensively in Brazil, the United States, and the European Union (especially Germany).

Biofuels account for over 3% of global transportation fuel. As oil output declines in the coming century, many scientists and economists expect that number will grow.

- Ornamental crop;

  Landscape gardening harvests ornamental crops such as dogwood and azalea. Ornamental plants are often grown in nurseries and purchased for use in household or commercial settings. Ornamental crop cultivation has a long history. The Netherlands' tulip harvest, for example, has become an emblem of the country.

  Ornamental crop cultivation is becoming a major source of income in many developing nations. Kenya, for example, is a significant rose and carnation exporter. Kenyan flower farmers have set up shop at the beaches of Lake Naivasha and Lake Victoria, where the land is rich and the water is plentiful and clean.

  Kenya's massive flower businesses, on the other hand, are wreaking havoc on lake ecosystems. Growers use lake water to irrigate their blooms, drastically reducing the amount of freshwater available for consumption and hygiene. Growers also use a lot of fertilizers and insecticides to keep their blooms looking beautiful during the export process. These pollutants frequently overflow into lakes, putting aquatic animal and plant life at jeopardy.

- Industrial Crops;

  Rubber and tobacco are two examples of industrial crops that are grown for use in factories and machineries. All crops utilized in the manufacture of industrial commodities, such as fiber and fuel products, are classified as industrial crops.

  Rubber is made naturally from several plants, but the Hevea tree, which is native to the Amazon area, is the most common source. The latex of rubber is collected. The inner bark of the Hevea tree contains latex, which is a very tough fluid. Taping the bark with a sharp knife and collecting the latex in cups is how latex is produced. Latex produces solid rubber lumps known as curds when combined with chemicals. Rubber curd sheets are formed by pressing them between rollers to eliminate excess moisture and produce sheets. The sheets have been folded and are ready to use. Tires, machine belts, shoe soles, and other items are packed and transported with the sheets.

Civilizations have utilized rubber for thousands of years. Rubber was first used to make balls for use in sports during the Olmec Empire in what is now Mexico. Rubber is still utilized in the production of durable toys, footwear, floors, balloons, and medical supplies today.

The majority of the world's rubber is currently produced by Hevea trees relocated to southern Asia. Thailand, Indonesia, and Malaysia are the countries having the most rubber crops. The worldwide demand for rubber has risen because of globalization. The rising demand for natural rubber has exacerbated forest degradation in southern Asia [4].

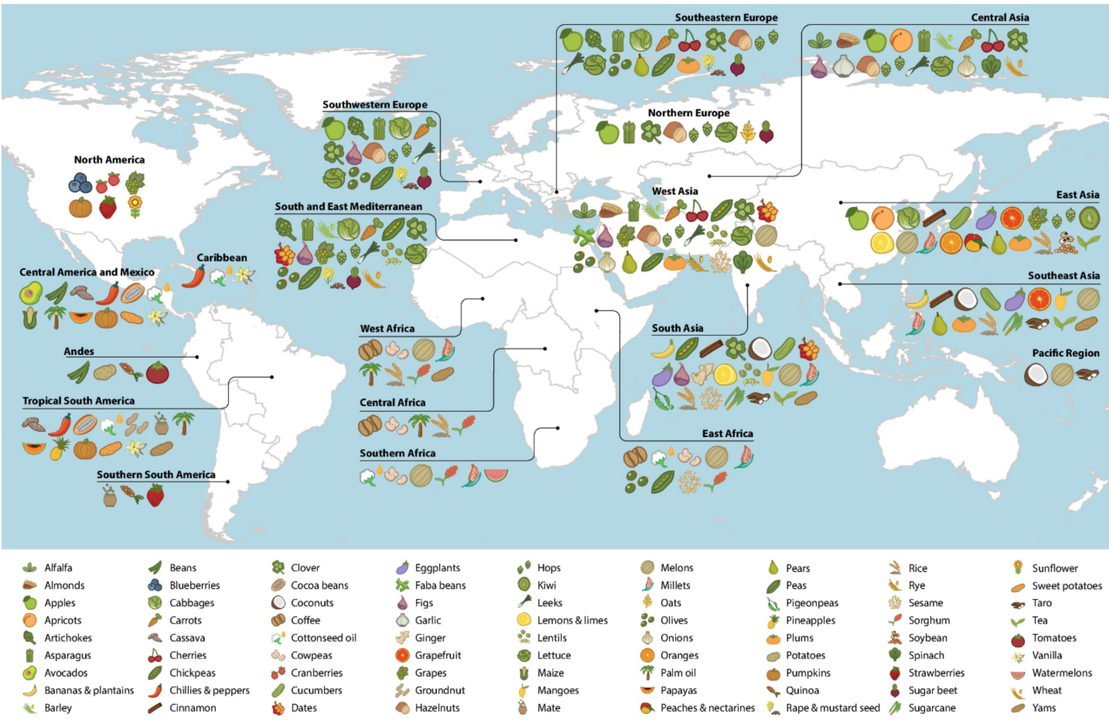


Figure 2.2: Crops plantation around the world.

Chapter 3

IMPROVING PRODUCTIVITY AND ENVIRONMENTAL SUSTAINABILITY

In this chapter we discuss how certain techniques may help a crop grow and improve different aspects of environmental sustainability or resource quality. The extent to which farmers have implemented the measures is unknown. If data is available, it will be discussed. However, a practice in and of itself may help with sustainability. However, it may have a detrimental impact on another aim; therefore, the drawbacks. Each practice's advantages and disadvantages are also highlighted. A farm is a collection of interconnected systems. Environmental circumstances, management, and the interrelationships between them, the environmental impact, efficiency, and effectiveness of biological activities are all determined by biological processes, and the farm's resiliency some of the drawbacks of specific techniques. If a complementary technique is followed, it may be possible to solve the problem.

In another words, combining the expected outcomes of numerous agricultural techniques is not the same as simply adding the expected outcomes of individual activities. To comprehend and harness complex processes, many in the scientific community have adopted a "systems" approach, which stresses the connectedness and interactions of components and processes across many scales. Agriculture and its component farming systems are analyzed holistically in "systems agriculture," which is an approach to agricultural research, technology development, or extension. In Chapter 7, an agricultural model system is used to demonstrate how systems research is carried out and how techniques may be combined to meet numerous environmental, economic, and social sustainability goals. The sections that follow focus on a succession of actions that make up a crop and emphasize specific practices that are considered as improving sustainability or have the potential to do so [5].

3.1 Soil Management

Soil management for sustainability is a complicated process that necessitates a complete understanding of its physical, chemical, and biological properties, as well as their interconnections. Soil management is an important part of sustainable agricultural production techniques because it results in healthier crops and animals that are less vulnerable to pests and illnesses. It provides a variety of key ecosystem services, including reduced nitrogen runoff and increased water storage capacity. Physical, chemical, and biological deterioration can occur as a result of poor soil management. Soil management is essential for farming systems to be environmentally sustainable [5].

The goal of good soil management is to:

- Maintain or increase the amount of organic matter in the soil.;
- Increase soil aggregates to improve soil structure. The soil aggregates would improve the soil's water-holding capacity.;
- Keep erosion to a minimum. Wind erosion may be reduced, which would enhance air quality. By minimizing sediment loading, a reduction in water and tillage erosion would enhance water quality.;
- Increase the variety and activity of soil microbes.;
- Reduce the number of diseases that are spread via the soil.;

3.1.1 Conservation Tillage

Conservation tillage is a tillage strategy that reduces plowing intensity and retains plant residues to produce a favorable soil environment for producing a crop while conserving soil, water, and energy resources. Before choosing tillage techniques, farmers must consider the advantages and disadvantages of each one.

The most important advantages of conservation tillage techniques are:

- Reduces erosion, which keeps upland soils productive.

- Maintains a favorable soil temperature.
- Increases the soil's water-holding capacity.
- Increases the efficiency of water use.
- Increases the efficiency with which nutrients are used.
- Reduced fuel and labor consumption.

With some conservation tillage techniques, however, herbicides may be used more often. Herbicide labels do not modify suggested amounts based on tillage system, although in some tillage systems, tillage may not be an option for weed management [6].

Below there are conservation tillage techniques with advantages and disadvantages for each one.

Plow

Advantages:

- Suitable for soils with poor drainage.
- Incorporation is excel-lent.
- Seedbed that has been well-tilled.

Disadvantages:

- Soil erosion is a major problem.
- Moisture loss in the soil is high.
- Timeliness is a factor to consider.
- The most expensive gasoline and labor.

Chisel

Advantages:

- Winter wind erosion is reduced due to the roughened surface.
- Poorly drained soils are well suited to this plant.
- Incorporation is excellent.

Disadvantages:

- There isn't much erosion control.
- Moisture loss in the soil is high. For residual flow, shredding maybe required.
- Fuel and labor needs are moderate.

Disk

Advantages:

- With greater residue, there is less erosion.
- It's well-suited to well-drained soils.
- Incorporation is excellent.

Disadvantages:

- More activities with less erosion control.
- Water loss in the soil is high.
- Soil structure is degraded.
- Wet soil compacts.

Ridge Plant

Advantages:

- Furrow irrigation or poorly drained soils benefit greatly from this product.
- Ridges soon warm up and dry out.
- It's ideal for organic farming.

Disadvantages:

- There will be no incorporation.
- Annual row crops are required.
- It's possible that wheel spacing,and other mechanical changes are required.
- Creating and maintaining ridges is a difficult task.

Strip-till

Advantages:

- The residue-free strip that has been tilled heats up fast.
- Nutrient injection into the row region.
- It thrives on poorly drained soils.

Disadvantages:

- The cost of the pre-planting procedure.
- Strips may become overly dry, crust, or degrade without leaving any behind.
- Crops that have been drilled are not suitable.
- In rainy falls, timeliness is essential.
- Costs of RTK guidance are possible.

No Till

Advantages:

- Erosion control is excellent. Moisture conservation in the soil fuel and labor expenditures are kept to a bare minimum.
- Improves the structure and vitality of the soil.

Disadvantages:

- There will be no incorporation.
- Herbicide use has become more reliant.
- On poorly drained soils, soil warming is slow.

3.1.2 Cover Cropping

Cover cropping is the use of vegetative crops like clover or vetch to avoid soil erosion, suppress weeds, and deliver nitrogen to a following crop. Ground cover is provided by cover crops, which are produced in rotation with cash crops to preserve the soil. They may also be tilled into the soil to retain soil organic matter and feed nutrients to succeeding crops (green manures), or they can be used to trap surplus nutrients in the soil profile following the harvest of the primary crop to reduce leaching losses. In orchards, perennial cover crops can be employed as ground coverings [7].

Advantages	Disadvantages
Reduce soil erosion, increase residue cover	Planted when time and labor is limited
Increased water infiltration and soil organic carbon	Addition costs (planting and killing)
Wildlife habitat and landscape aesthetics	Difficult to incorporate cover crops with tillage
Enhanced field traffic ability and improved soil physical properties/reduced soil compaction	May increase disease risks
Recycle nutrients, fix nitrogen with legumes	May increase insect pests
Improve weed control, beneficial insects, disease suppression	Allelo pathic effects

Table 3.1: Advantages and disadvantages of using cover crops

3.2 Crop and vegetation diversity management

Crop diversity (varying the types of crops planted and containing diverse genetic variants) is a risk management strategy used on farms. Crop and livestock integration can also help to achieve agricultural diversity. Crop diversification has been shown in several studies to minimize crop pests and diseases, preserve soil fertility, and improve water usage. The impacts of diversity, on the other hand, might vary depending on the type of diversity and the functional diversity present. Nonetheless, in many subsistence farming systems across the globe, large levels of crop diversification remain the principal way of risk management. Rotating crops, preserving genetic diversity, planting crops together, adding cover crops, and appropriately managing non-cropped land might improve the robustness and resilience of farming systems in the face of pest issues that are unpredictable, as well as changing market conditions [5].

One of the foundational tenets of sustainable agriculture is that the trade off between increased production and biodiversity loss is not unavoidable. Increasing crop diversity has the potential to increase sustainability, by meeting the following goals:

- Reduced pesticide and herbicide use.
- resilience of the system to adverse environmental conditions.
- Greater conservation of biodiversity.

- Improved soil fertility and soil organic matter.

3.2.1 Crop rotation

Crop rotation is the practice of planting crops in various parts of the field each year such that no one crop is grown in the same spot for two or more years. Crop rotation has several advantages, according to agriculturists and agronomists. It helps in increasing the soil fertility along with crop productivity [8].

Here's some advantages and disadvantages of using this technique:

Advantages	Disadvantages
• increase soil fertility • increase crop yield • Increases Soil Nutrients • Reduces Soil Erosion • Limits the Concentration of Pests and Diseases • Reduces the Stress of Weeds • Improves the Soil Structure • Reduces Pollution • Diversification and Reduced Cost of Production • The Nutrient Uptake Regulation	• It Involves Risk • Improper Implementation Can Cause Much More Harm Than Good • Obligatory Crop Diversification • Requires More Knowledge and Skills • The Difference in Growing conditions

Table 3.2: Advantages and disadvantages of using crop rotation

3.2.2 Intercropping

The agricultural technique of cultivating two or more crops in the same location at the same time is known as intercropping. It usually refers to the simultaneous planting of two or more distinct food crop species in the same field, although it can also refer to various types of the same crop species. Intercropping systems are widespread in tropical subsistence and small-scale farms because they improve crop genetic variety and lower the risk of crop loss. Intercropping is most linked with small-scale, sustainable, and organic farming systems in the United States; it is significantly less prevalent on large-scale automated farms.

Strip intercropping is the technique of planting two or more crops in strips that are wide enough for each to be handled independently but narrow enough for the strip components to interact. In principle, interactions between crop components (physical, biological, ecological, and managerial) increase biomass output while also providing important ecological services including nutrient cycling, biological pest control, and water and soil conservation. The problem with strip cropping is identifying the appropriate species assemblages to promote biological synergies while maintaining compatibility with agricultural equipment and conservation tillage methods [5].

Below the advantages and disadvantages [9]:

Advantages	Disadvantages
• Intercropping gives additional yield income/unit area than sole cropping. • It serves as a form of crop insurance in the event of a bad year. • Intercrops sustain soil fertility by using both layers of soil for nutrient absorption. • Controls weeds and reduces soil runoff. • Intercrops provide the other crop shade and assistance. • The intercropping technique makes optimal use of resources and boosts productivity. • It is more beneficial to intercrop with cash crops. • It reduces inter-crop competition, allowing for more agricultural plants to be planted per unit space.	• Yield decreases as the crops differ in their competitive abilities. • Management of I/c having different cultural practices seems to be difficult task. • Improved implements cannot be used efficiently. • Higher amount of fertilizer or irrigation water cannot be utilized properly as the component crops vary in their response of these resources. • Harvesting is difficult.

Table 3.3: Advantages and disadvantages of using intercropping

3.2.3 Cultivar mixture

The previous sections address crop species diversification in the perspective of diversity. This section looks at diversity in the perspective of mixing cultivars from the same species. Most crops in western agriculture are cultivated from clonally replicated planting stock or homogeneous, genetically identical seeds. Biological principles, on the other hand, imply that genetic variety within species and cultivars can improve population fitness and production [5]. below the advantages and disadvantages:

Advantages	Disadvantages
• Had higher productivity than monocultures • Increase crop yield and improve resistance to diseases • Control powdery mildews and rusts of small grains • Managing crop performance and the risk of pest outbreaks	• Added time and cost involved in the mixing • Loss of the opportunity to adjust management practices to the specific requirements of each variety • The use of noncrop vegetation on farms, requires farmers and operators to possess greater management skills and knowledge than unmixed cultivars

Table 3.4: Advantages and disadvantages of using cultivar mixture

3.2.4 Plant breeding and genetic modification

Genetic modification and conventional plant breeding is a method of altering the genetic composition of crops to generate crops with better qualities. GM does this by inserting a new gene or genes into a crop plant's DNA. Conventional breeding accomplishes this by combining plants with important features and choosing offspring with the appropriate mix of qualities as a consequence of specific gene combinations acquired from both parents.

Genetic crop enhancement is achieved through both conventional plant breeding and genetic modification (GM). For thousands of years, genetic improvement has been a key component of increased agricultural output. This is due to the fact that wild plants produce inferior yields. Plants that can compete for light, water, and nutrients with neighboring plants, protect themselves from being eaten and digested by animals, and disseminate their seed across large distances are favored by natural selection. These traits are in direct opposition to agricultural aims, which require plants to devote as much of their resources as possible to producing nutritious, easy-to-harvest goods for human consumption. Because of the striking disparity between what natural selection has generated and what produces a productive crop, we've utilized traditional breeding methods to transform plants that compete well in the wild into plants that perform well in agriculture for thousands of years. As a consequence, we now have crop types that are significantly more productive and nutritious than their wild parents yet compete poorly in the wild [10].

Table below shows the pros and cons for plant breeding and genetic modification [11].

Advantages	Disadvantages
• Contain more nutrients. • Grown with fewer pesticides. • Usually cheaper than their non-GMO counterparts. • May cause allergic reactions because of their altered DNA. • May increase antibiotic resistance.	• May cause allergic reactions because of their altered DNA. • May increase antibiotic resistance.

Table 3.5: Advantages and disadvantages of using Plant breeding and genetic modification

3.2.5 Molecular markers and genetic engineering in cultivar development

Plant breeding, which involves sexual recombination and phenotypic selection of plants with better features, is still the most common method for improving crops in both conventional and sustainable agricultural systems. Any breeding program must include field evaluations and selections. The invention and application of molecular or DNA markers—DNA sequences linked with certain genes or traits—has become commonplace in recent years in breeding programs for the selection of progeny in a variety of crops, including lettuce, maize, soybean, rice, wheat, cotton, tomatoes, cassava, and others. Marker-assisted selection (MAS) and breeding have the potential to revolutionize plant breeding by increasing selection efficiency and reducing the time and expense required to generate superior varieties. They can also make it easier to explore and use natural genetic diversity in older varieties, landraces, and wild relatives to broaden the genetic basis of crops and provide farmers additional options for future crop development [5].

Even though it is a contested field of breeding, genetic engineering of crop plants can help. The intentional altering of a plant's genome using recombinant DNA technology to transfer genetic material into a crop to give it a desirable attribute is known as genetic engineering. The gene or genes inserted might be from the same or other species, including bacteria and mammals. After the genes have been successfully delivered into a plant, the genes are subsequently incorporated into marketable kinds using traditional plant breeding procedures [5].

Advantages	Disadvantages
• Increasing production, enhanced insect and weed resistance, and improved drought tolerance have all improved output. • Increased yield and decreased pesticide use in many cases.	• Some of the environmental issues aren't specific to GE-based cropping methods. • In certified organic agricultural production systems, GE crops are prohibited, and there is substantial resistance to GE crops in Europe and other nations.

Table 3.6: Advantages and disadvantages of using molecular markers and genetic engineering

3.3 Water Use Management

Water management is vital for meeting the sustainability goals of saving water resources. The timing, intensity, and volume of water applied by precipitation, irrigation, or combination for all agricultural fields are the "drivers" for regulating water usage. These variables, together with evapotranspiration, the quantity of water that evaporates from the soil surface and transpires from the crop, determine the amount of surplus water that drains from a field at any time and place.

Because irrigation is the most common type of water usage, techniques that increase water application efficiency and reduce water loss are the most efficient in conserving water and energy in areas when supplies are scarce. Water-use efficiency, on the other hand, is a complicated topic with many various meanings. Comparing the amount of water extracted from a river or aquifer to the amount utilized beneficially by the crop may be most valuable from a systems viewpoint. Conveyance from the source to the farm, uniformity of application to the crop, and drainage losses following treatment are all factors that impact performance. Many systems across the world work badly, with just 30 to 50 percent of the water withdrawn being used by the crop. However, water wasted in this manner from one farm may be useful elsewhere, thus when calculating genuine water savings, it's crucial to include basin wide efficiency. To increase the long-term sustainability of water usage in agriculture, precipitation can be caught, or water reused in addition to regulating water use [5].

3.3.1 Irrigation Scheduling

Irrigation scheduling is the method used by irrigation system managers to determine the appropriate watering frequency and duration. Irrigation scheduling is important because it allows the irrigator to deliver the exact amount of water needed to accomplish the desired result. This improves the efficiency of irrigation. Accurate measurement of the volume of water applied or the depth of application is a vital component. Without knowing how much water was applied, a farmer can't manage it effectively.

To get the most out of irrigation scheduling and management, uniform water distribution over the field is critical. Over or under irrigation is avoided with precise water application. Overwatering costs water, energy, and labor; it leaches costly nutrients below the root zone, out of reach of plants; and it lowers soil aeration, lowering crop yields. Irrigation strains the plant, resulting in lower yields [12].

Here ‘s the advantages offered by irrigation scheduling:

- It allows the farmer to arrange water rotation across fields in order to reduce crop water stress and increase yields.
- It saves the farmer money on water and labor by reducing irrigations and maximizing the utilization of soil moisture storage.
- Surface runoff and deep percolation (leaching) are kept to a minimum, lowering fertilizer expenditures.
- It improves agricultural yields and quality, which boosts net returns.
- It reduces drainage needs, which reduces the risk of waterlogging.
- Through regulated leaching, it aids in the regulation of root zone salinity issues.
- It generates additional profits by repurposing "saved" water to irrigate non-cash crops that would otherwise go unwatered during water shortages.

3.3.2 Gravity Irrigation

One of the most efficient ways for agriculture to save water is to improve the consistency of irrigation water application. Nonuniform irrigation wastes water because it must be provided at rates much surpassing those required by the areas of the field getting the most water to avoid yield reductions in the parts receiving less water.

Gravity irrigation does not use pumps; instead, water flows and is distributed by gravity. Water is distributed laterally across the entire field or into furrows using gravity flow devices. To decrease water losses in gravity-flow systems, various land treatments, system enhancements, and water management strategies have been devised. On-farm water conveyance enhancements that increase uniformity of delivered water and minimize percolation losses and field runoff are common features of improved gravity systems. Only 20% of the acres covered by open ditches are served by improved ditch systems, which are walled with concrete or another impermeable substance. Many viable technologies or management enhancements, such as alternative row irrigation, furrow modification, tailwater reuse, or soil supplements, are not widely used, indicating that improved water management techniques for gravity irrigation have tremendous development potential [5].

3.3.3 Sprinkler Irrigation

Sprinkler irrigation is a type of irrigation water application that mimics natural rainfall. Pumping is used to transfer water through a system of pipes. The water is then blasted into the air by sprinklers, breaking up into little water drops that fall to the ground. Sprinkler irrigation is a method of pressured irrigation that uses mechanical and hydraulic systems to distribute water to the soil surface, simulating natural rainfall [13].

Advantages of sprinkle Irrigation System:

- Affordable and simple to set up.
- It is easier to monitor water than it is to use a surface watering system.
- There will be less interference with farming and less land loss.
- It is possible to apply a high volume of material on a regular basis.
- Mechanization and automation are simple to implement.
- By injecting chemicals into irrigation water, fertilization and chemigation can be utilized for plant nourishment or pest control.

On the other hand, there are some disadvantages of this system which it's:

- Operating costs are high.
- When there is a lot of wind, water will drift.
- It is necessary to have a reliable water supply.
- It's possible that saline water will be a concern.
- Sand, debris, and a substantial amount of salt must be removed from the water to prevent closure of sprinkle nozzles.
- Crop leaves can become scalded.

3.3.4 Trickle or Drip Irrigation

Trickle or drip irrigation uses low-pressure applicators such as orifices, emitters, porous tubing, and perforated pipe to provide water directly to the root zone of plants. The applicators might be placed above or below the ground's surface. Over the last three decades, switching to trickle or drip irrigation has been the most significant strategic increase in water-use efficiency and energy savings. For those crops where precision water application is used, it results in a large conceptual and process-related shift in energy use. Most orchards and vineyards are changing to these systems, and practically all freshly planted ones, as well as a wide range of annual horticulture crops, are adopting precision water application. The application tubes are placed in close proximity to the tree or vine of crop plants, and water is applied as needed, monitored by a host of newly engineered moisture and plant stress-sensing devices [14].

The following are some of the benefits of drip irrigation:

- Weed growth is unlikely, as water is applied directly to each crop.
- Seed and yield germination are aided by drip irrigation.
- It is particularly handy for fertilizer applications.
- This kind of irrigation conserves water.

There are certain drawbacks as well, such as:

- The installation of a drip irrigation system is highly costly.
- Because emitters are prone to clogging, it is necessary to clean the pipes on a regular basis.

- Skilled personnel are required in water management regions.
- Insects and rodents chewing on tubing can cause water leaks. Mowers and trimmers can slice tubing.

3.3.5 Regulated Deficit Irrigation

Deficit irrigation occurs when water is applied below the crop's complete evapotranspiration requirements, allowing it to endure minor water stress. Deficit irrigation has been demonstrated in studies to be effective on a variety of crops, including cotton and potatoes, with little or no negative impact on output. While uncontrolled deficit irrigation occurs, regulated deficit irrigation (RDI) places crops in a moisture deficit during stress-tolerant growth phases to reduce output losses [5].

On the other hand, only a few crops are appropriate for managed deficit irrigation, and producers must have a thorough grasp of how crops respond to water stress at various phases of development and in various environments. Pistachios, for example, are more resistant to stress during the shell-hardening stage than they are during the blooming or nut-filling stages [5].

3.3.6 Water Reuse

Several low-quality water sources might be used to supplement the supply of water for agriculture. Domestic wastewater, if properly recovered, may be utilized for several agricultural purposes, such as irrigation water or to free up high-quality water that was previously being used for an activity that can use reclaimed water without putting the public's health at risk. Wastewater offers just a tiny percentage of the national water resource for agriculture at the moment. Saline water has the ability to supplement agricultural water consumption, especially through the reuse of drainage water on more salt-tolerant species or the utilization of cyclic rotations of excellent quality and saline water to cultivate a variety of sensitive and tolerant crops.

The circular economy is aided by the reuse of water for agricultural irrigation since nutrients may be collected from reclaimed water and applied to crops using fertilization techniques. This indicates that reusing water might potentially lessen the requirement for further mineral fertilizer applications.

The biological and chemical quality of recovered water is the biggest problem when it comes to reuse. A wastewater treatment system's ability to remove microorganisms and anthropogenic pollutants is critical. To decrease the likelihood of dangerous contaminants entering an agricultural production system, the recovered water would have to be closely monitored [5].

3.3.7 Small Dams

A dam is a hydraulic structure built across a river to hold water on the upstream side of the river. It's an impermeable barrier placed over a natural stream to create a reservoir.

Large dams have prompted suggestions for alternate water collection methods due to their numerous negative environmental implications. A recent committee of the National Research Council proposed that, in addition to minor surface water storage strategies utilized extensively on agricultural lands, controlled subsurface storage and recovery should be seriously examined as a tool in a water manager's armory. Dams benefit the environment in a variety of ways. Dams provide clean water, improved sanitation, greater food (crop and fish) production, irrigation, flood protection, energy generation, mine tailings and debris control, as well as recreational and environmental advantages of reservoirs [15].

Here's the irrigation advantages of constructing a water dam are described in this way, crops and vegetation require irrigation for evapotranspiration. Irrigation uses a large portion of the water stored in dams. People are more likely to employ more farming lands if there is a steady supply of water for irrigation. This boosts the growth of the food supply [15].

On the other hand, Excess nutrients in slow-moving water impounded or held from upstream agricultural usage can lead to algal blooms, nuisance-level aquatic plant growth, and oxygen loss due to organic matter decomposition. Small dams, on the other hand, can provide water storage and environmental advantages that outweigh the drawbacks with adequate management and upkeep. Another issue is siltation and low storm water storage, which can lead to spillway or dam collapses. Sediment pools have filled, and structural components on some of these dams have deteriorated. Rehabilitation or the use of contemporary design and construction technologies will be required to address public safety, environmental, and social problems [15].

3.4 Water Quality Management

An important objective for pushing agriculture toward sustainability is to reduce contamination of surface and ground water. Agricultural runoff and leaching contaminate ground water with agrichemicals, while sediment and nutrient runoff pollutes surface water. Surface drains (for example, waterways and drainage canals), mitigating features (for example, buffers and vegetative filter strips), and subsurface tile drainage are some of the most important landscape features affecting nutrient losses, and whether those features are in place because they affect the relative volumes of surface runoff and subsurface drainage. On a smaller scale, the rate of water penetration in soil and rainfall are the most critical elements that govern the volume and timing of surface runoff [5].

3.4.1 Drainage Water Management System

Drainage water management (DWM) is a practice in which the outlet from a conventional drainage system is intercepted by a water control structure that effectively functions as an in-line dam, allowing the drainage outlet to be artificially set at levels ranging from the soil surface to the drains' bottoms, as shown in the diagram below.

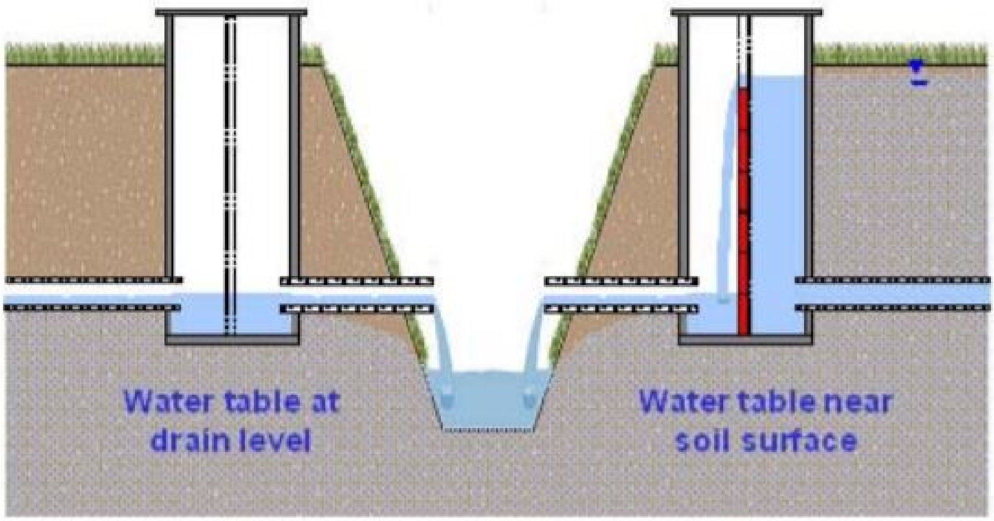


Figure 3.1: Drainage water Management technique.

Drainage is an environmentally beneficial technique when it is utilized to restore salinized and waterlogged soils because the land is returned to its full productive potential. Other benefits of adapting subsurface drainage systems to act as sub-irrigation or controlled drainage systems include a reduction in nitrate contamination [16].

The following is a summary of the field-scale advantages of drainage:

- Drainage encourages the growth of beneficial soil microorganisms and enhances soil tilth.
- Drilled land has reduced surface runoff and soil erosion.
- Field machine trafficability is improved, which lowers soil structural damage. Soil compaction is minimized, and field equipment activities take less energy. Field works can also be completed more quickly thanks to drainage. As a result, the growing season may be extended, and crops can mature fully.
- Improved water management and plant nutrient absorption result in higher crop yields.
- Higher-value crops can be grown, and new and improved farming techniques can be introduced.
- Land value and production are both increasing in general.
- Farm income is higher, and income volatility is lower.
- Drainage in the crop root zone promotes a favorable salt and air environment.

DWM has certain restrictions in terms of use. Some current drainage systems were not planned or constructed in such a way that improvements are simple to implement; nevertheless, subsurface drainage systems may be upgraded with all of the equipment required to run and maintain the DWM practice properly. There is little risk of production loss because DWM systems are normally handled during non-growing season months or between crop rotations [5].

So, there are several benefits to subsurface drainage. In many locations, it is required to maintain agricultural productivity, although it can increase nutrient loss. To limit the transmission of P and nitrogen to surface water bodies, solutions to water quality concerns are required. To assist solve this water quality issue, best management strategies such as nutrient management, cover crops, conservation tillage, controlled drainage, saturated buffers, wetland, denitrification beds (woodchip bioreactors), and two-stage ditches are available. Other technologies, such as P-filters containing P-adsorbing medium, are also being looked into as a possible option [5].

3.4.2 Wetland

Wetlands are nature's flood control and water purification system. They collect extra water from a river flood or a storm and gently release it back into the river after the storm passes. Wetlands remove surplus nutrients and pollutants from the environment while also providing home for a variety of creatures. Wetlands can be swamps, bogs, and marshes along a shoreline in nature. Wetland nature reserves have undergone substantial rehabilitation and building during the last two decades. Wetland nature reserves that have recently been built provide both wastewater treatment and animal habitat.

For thousands of years, wetlands have been exploited for agriculture. They provide a variety of important ecological services, including the supply of food and clean water, soil retention, and nutrient cycling. However, the importance of these services is sometimes overlooked. The draining and reclamation of wetlands for agriculture has been prevalent in some locations, but the important interdependencies between agriculture and healthy wetlands are becoming more widely recognized.

Wetlands provide a variety of ecosystem services that can assist agriculture, including supporting fertile soils, reducing erosion, retaining sediments and nutrients, and reducing the risk of salt and acid sulphate soils [5].

On the other side, there are some cons effects on environment which spread into four phases [17].

Disease

Swamps and other wetlands serve as breeding grounds for mosquitoes and other illnesses. Mosquito populations can be somewhat reduced in man-made wetlands.

Land Use

Constructed wetlands are large-scale projects that need a lot of area. Many countries have had programs of draining and filling natural wetlands to allow for urban growth in the past. Flood fortifications included levees, heightened riverbanks, and sea walls.

Methane Production

Methane has ten times the warming potential of carbon dioxide in the atmosphere, making it the most potent greenhouse gas for global warming. The anaerobic decomposition of organic materials in wetlands produces around a quarter of the world's atmospheric methane.

Inadequate Remediation

Constructed wetlands are incapable of treating today's highly hazardous wastewater. Such trash must be processed in specific facilities, which may detract from a nature reserve's aesthetic appeal. Residual contaminants might be harmful to the reserve's animals.

3.5 Nutrient Management

Nutrient management is the act of controlling the amount, source, timing, and method of nutrient administration in order to maximize agricultural output while reducing nutrient losses that might cause environmental issues. It entails assessing the quantity of nutrients existing in the soil, estimating the amount of nutrients required by the crop, accounting for all potential sources of nutrients, and then adding manures, composts, irrigation water, or inorganic fertilizers to fulfill the crop's nutritional requirements. It also employs site management strategies to improve or maintain soil quality, reducing the risk of erosion and nutrient movement into surface water or groundwater.

Because it impacts nutrient retention and water flow through the soil, soil quality is an important part of nutrient management. In the shot on the right, biosolids being sprayed to an agricultural field.

The objectives of a successful nutrient management program are twofold: provide sufficient nutrients for crop or animal development throughout their life cycle and reduce the negative environmental effects of nutrient losses. This section examines the creation of nutrient budgets to aid fertility management by balancing inputs and desired outputs (products) while minimizing unwanted outputs (losses) into the environment. Following that, the many types of fertility inputs utilized in crop and pasture production as well as the challenges associated with their usage are outlined. This section also includes instances of creative approaches to nutrient management, as well as animal waste disposal and recycling.

To promote sustainability, an effective on-farm nutrient management strategy would strive to meet the following goals:

- Maintain or improve soil fertility.
- Reduce the usage of off-farm nutrient inputs, particularly synthetic fertilizer, to reduce fertilizer production energy.

- Ensure that nutrients are used efficiently, decreasing nutrient leaching and runoff while also increasing water quality.

- Ensure that on-farm nutrient sources are used and recycled effectively.

To achieve desired crop growth and output, farmers must add nitrogen, phosphorous, potassium, and other nutrients. Excessive fertilizer application, on the other hand, might have detrimental environmental consequences. Nutrients that aren't utilised efficiently by crops or maintained in the soil might seep into groundwater and go from agricultural land to surface waterways. Excess nitrogen, in the form of nitrate, can, for example, leak into groundwater.

Nutrient management is used by almost all farms. A basic stage in nutrient management is using soil testing to calculate the quantity of inorganic fertilizer required for a crop. As the cost of inorganic fertilizer rises, more people are turning to nutrition sources such as legumes, manures, composts, and other wastes to help them save money. Many farmers find yearly changes in yield, crop response, climate, soil types, and manager decisions perplexing, but well-kept records and field experience may help them comprehend and explain them [18].

3.5.1 Mass Balance for Nutrient Management

By displaying patterns of excessive or insufficient inputs for different nutrients during crop rotation cycles, nutrient mass balances (most typically for nitrogen and phosphorus) can assist growers establish a holistic approach to nutrient management. The right nutritional balance can then be achieved by adjusting the inputs. To offer information on nutrient input excess or deficit and consequences for water quality, mass balance calculations have been performed at the field, farm, watershed, and national scales. Several studies at the field scale have found agricultural techniques and systems with higher nitrogen inputs than nitrogen outputs. To calculate the N balance, all these studies employ mass conservation [5]:

Inputs − outputs − delta soil residual mineral N = residual

where output refers to nutrients extracted through harvesting as well as nutrients lost to the environment. Partial nutrient budgets are frequently used, especially for annual budgets, where the residual is assumed to be zero and changes in soil mineral nitrogen may or may not be considered, due to the difficulty of measuring all individual output pathways into the environment and thus calculating the residual term. The following is a revised equation for estimating probable undesirable losses from a field or farm [5]:

Inputs − harvest outputs = potential loss into the environment

3.5.2 Soil and Tissue Sufficiency Test

A lot of work has gone into improving soil and plant tissue sufficiency testing to assist predict the quantity of fertilizer inputs required to promote excellent crop development. Soil testing are frequently performed prior to planting or at early development phases such as pre-side dressing, whereas plant tissue tests are frequently performed numerous times during the season to allow for modifications in fertilizer treatments later. Various agricultural canopy measurements are also utilized, such as leaf chlorophyll and canopy reflectance. There are several great articles on the subject that examine the challenges surrounding soil and tissue testing as well as summarize the numerous tests produced for various crops.

Depending on the crop, the most effective test differs. Both experiments revealed that yield had a significant linear connection. In the case of sugar beets, the strongest predictor of yield was a petiole NO3 – test. However, soil testing has limitations in that they do not account for factors that influence the likelihood of real field loss and water quality problems. Because of these limitations, more complex measures have been developed, such as the phosphorus index, which considers a combination of soil test, rate, and application method for phosphorus from fertilizers and manure, as well as soil erosion, runoff class, distance from surface water bodies, and irrigation erosion [5].

3.5.3 Nutrient Management Plans and Best Management Practices

A nutrient management plan (NMP) as managing the amount, source, placement, form, and timing of the application of nutrients and soil amendments [5].

The purpose of NMP are:

- To provide enough nutrients for plant growth.
- To effectively use manure or organic by-products as a source of plant nutrients.
- Agricultural non-point source contamination of surface and ground water resources should be minimized.
- To preserve or improve soil's physical, chemical, and biological properties.

NMP will assist in the cost management of commercial fertilizer and animal manure inputs. It will also assist to enhance the quality of surface water. A nitrogen (N), phosphorus (P), and potassium (K) NMP should consider all potential nutrition sources, including but not limited to [19]:

- Legumes and crop rotation contribute nitrogen.
- Animal dung and organic by-products.
- Wastewater
- Commercial fertilizer
- Nutrient availability in the soil
- Water used for irrigation

The following component are generally found in all NMPs [19]:

- An aerial snapshot or map of the field, as well as a soil map.
- Crop rotation is a current and/or planned crop production sequence.
- Analyzed samples of soil, plant, water, manure, or organic by-products.
- Crop rotation yield potentials that are realistic.
- A comprehensive list of all nutritional sources.
- Nutrient rates, timing, form, and mode of delivery, as well as incorporation timing over the plan's duration.
- The location of designated sensitive sites or resources, as well as the nutrient management limits that go along with them.
- Implementation, operations, maintenance, record-keeping, and a detailed field-by-field nutrient budget for Nitrogen, Phosphorus, and Potassium for the rotation or crop sequence are all included.
- A declaration stating the plan was created using current standards as well as any applicable federal, state, or municipal legislation or policies, and that any changes to these criteria may need a plan amendment.

Best management practices (BMPs) are procedures or approaches that have been shown to be the most effective and feasible means of attaining a goal (such as preventing or limiting pollution) while making the best use of a property's resources. Nutrient BMPs are designed to increase crop output while reducing the quantity of nutrients that leave the land, either through surface runoff from irrigation or stormwater, or by leaching into groundwater. The quantity, source, kind, placement, and timing of nutrients supplied to a crop are all considered in nutrition BMPs. [20]

BMPs for nutrient management include the following:

- To maximize plant development and minimize excessive fertilizer, evaluate irrigation water, soils, growing media, and plant tissue.
- Using effective fertilizer and leaching techniques.
- Always Avoiding fertilizer spillage throughout transportation, storage, and application.

3.5.4 Nutrient Input

Nutrient Inputs is an important thing in nutrient management which is an essential part of sustainable agriculture. Chemical fertilizers of various formulations are the most extensively utilized fertility inputs in agriculture today. There is a wealth of information available on determining optimum fertilizer input amounts for various crops, as well as numerous soil and tissue tests to assess nutrient adequacy during the growing season. Split applications and slow-release fertilizers can also aid in the synchronization of nutrient supply and crop demand. However, this section concentrates on three types of nutrient inputs that may be produced on-farm and can help with nutrient cycling: legumes, animal dung, and compost [5].

Twenty nutrients have been identified as essential for crop development. Plants require considerable amounts of nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium, which are referred to as macronutrients. Micronutrients such as boron, copper, manganese, molybdenum, and zinc are also required for plant health [21].

Although minerals such as nitrogen, phosphorus, potassium, and other nutrients are necessary for optimum crop development and yields, too much of a good thing may be harmful. Excess nitrogen, for example, can seep into groundwater as nitrate and cause issues with drinking water. Excess phosphorus in surface water can result in algal blooms. Crop development might be hampered by too much copper or zinc. As a result, fertilizer treatments should be carefully monitored to ensure that concentrations are appropriate but not excessive [21].

3.5.5 Legumes

Rhizobium, a root-nodule bacterium that fixes atmospheric nitrogen to ammonium and so acquires nitrogen from the soil and the atmosphere, has a symbiotic connection with legumes. Amino acids and proteins are absorbed into the biomass of legumes as fixed nitrogen. Because part of the fixed nitrogen is returned to the soil through crop residue integration and direct release into the soil via root exudation and root death, crop rotations that contain actively fixing legumes can minimize nitrogen fertilizer demands. Leguminous cover crops, as stated in the previous section on cover crops, can be utilized as green manures to increase soil fertility [5].

Legumes fix atmospheric nitrogen, release high-quality organic matter into the soil, and help soil nutrients circulate and retain water. Legumes offer a lot of potential for conservation agriculture because of their numerous uses. They may be used as a growing crop or as crop leftover [22].

Among the several essential advantages legumes provide to society, their contribution to climate change mitigation has received little attention. When compared to agricultural systems based on mineral N fertilization, legumes can:

- Reduce greenhouse gas (GHG) emissions such as carbon dioxide (CO2) and nitrous oxide (N2O),
- Play a key role in carbon absorption in soils
- Reduce total fossil energy inputs in the system.

Grain legumes' functions and value in the context of agricultural sustainability might be strengthened through new research possibilities.

Selection of legume species and cultivars that can be efficiently introduced across diverse cropping systems will be a crucial problem in the future. A key aspect is to strike a balance between yield, which provides a financial return, and environmental and agronomic advantages.

Some priority areas appear to have emerged. Grain legume nitrogen fixation activity should be assessed in relation to soil, climatic, plant, and management factors to determine the optimal technique for achieving the greatest results. In this regard, the host plant's capacity to retain fixed nitrogen appears to be a key factor in boosting nitrogen fixation input. A special emphasis should be placed on the research of abiotic stress constraints, particularly water deficiency, salinity, and heat shocks, which need to be thoroughly investigated.

In future agricultural systems, legumes that can recover scarce types of soil phosphorus might be valuable assets. As a result, those legumes that can absorb phosphorus from forms that are ordinarily inaccessible should be explored further, as phosphorus is an expensive and limited resource in many cropping systems.

Grain legumes are expected to play a significant part in future cropping systems, owing to rising demand for plant products such as protein and oils, as well as increased economic and environmental constraints on agro-ecosystems [22].

3.5.6 Animal Manure

Raw manure from animals is frequently utilized as a crop fertilizer or soil supplement. Substituting animal dung for synthetic fertilizer has the potential to boost carbon sequestration while also lowering the amount of fossil energy used to make synthetic fertilizer [5].

There are some beneficial of using these organic fertilizers where it summed up like this [23]:

- Soil structure: improves because of the organic matter in organic fertilizer, and the soil's capacity to store water and nutrients improves as a result.
- Microbes thrive: Synthetic fertilizer is made up of carbon-free chemical compounds. These chemicals can be disruptive at times, and they are inaccessible to microorganisms. Organic fertilizer, on the other hand, is high in organic content, which aids microorganism growth. Carbon, together with nitrogen, phosphorus, and potassium, is part of the chemical composition of organic fertilizer, and it is the carbon, along with nitrogen, phosphorus, and potassium, that feeds microorganisms and allows them to make nutrients accessible to plants in a biological process that occurs naturally.
- Sustainable and environmentally friendly: Synthetic fertilizers pollute our rivers, causing harm to marine life and degrading water quality. Organic fertilizers are related with soil structure and do not flow off as easily (if at all). Organic fertilizer also improves species richness by 30% when compared to synthetic fertilizer, according to the Organic Trade Association.
- Reduce fertilizers and pesticides: Organic fertilizer is more expensive than synthetic fertilizer, but it can reduce pesticide use and total nitrogen, phosphate, and potassium requirements. Organic fertilizer can be cost neutral or even cost saving due to the reductions.
- Plant damage threat avoided: Some synthetic fertilizers can harm the leaves and roots of plants. Organic fertilizers are less likely to cause this.

While on the other hand, there are some disadvantages of using organic fertilizers which summed up like this [23]:

- Not all products are created equally: Many organic goods generate variable effects since they are not all made equal. Review any university studies or case studies to ensure you're choosing a product that has been well evaluated by the industry.

- Nutrient levels are low: Organic fertilizer frequently has a poor nutritional content. Furthermore, because the nutrients are frequently complexed in organic chemical structure, utilizing organic fertilizer may not generate the same burst of color as using chemical fertilizer. Using organic fertilizer is a method, not a one-time event.

- DIY compost is complicated procedure: While it is possible to make your own compost, it is a dirty and time-consuming procedure that frequently results in an uneven product and end-result.

3.5.7 Compost

Compost is a decomposed organic substance created from farm manure, sewage sludge, agricultural residues, or food wastes. "An aerobic process of breakdown of organic materials into humus-like compounds and minerals by the action of microorganisms mixed with chemical and physical processes," according to the definition of composting. Composting agricultural manure and other organic materials stabilizes their nutritional content and produces a product that is more manageable than raw manure. Although compost is not as excellent as raw manure for providing instantly available plant nutrients, a well-matured compost distributes nutrients slowly and so minimizes losses. The quality of compost generated is highly influenced by the raw materials used to make it and the conditions under which it is made; hence, quality criteria for commercial compost have been created. Quality requirements, for example, are based on a set of tests that include respiration, temperature, carbon-to-nitrogen ratio, visual and olfactory qualities, seed germination, and a maturity index [5].

The following are the key benefits of sludge composting [24]:

- Compost is high in nutrients and may be used for a variety of purposes, including landscaping, topsoil blending, and growth medium.

- Due to the loss of ammonia during composting, compost contains less nitrogen than bio solids from other stabilization procedures. Compost, on the other hand, releases nitrogen more slowly and is available to plants for a longer length of time, which is more in line with plant absorption requirements.

- Sludge that has been properly composted can fulfill the standards for class A bio solids and be sold to distributors and the general public.

- Sandy soils benefit from compost because it enhances the water content and retention.

- Clay soils benefit from compost because it improves aeration and water penetration.
- Windrow and aerated static pile operations are easy to run and offer the flexibility to manage varying feed characteristics and peak loads. They also need very basic mechanical equipment.
- In-vessel methods need a little amount of space and can be used to manage smells.

The following are the major disadvantages of composting:

- Composting in windrows and aerated static piles takes up a lot of space, and odor control is a regular issue.
- Windrow and aerated static pile composting are affected by ambient temperatures and meteorological conditions.
- In-vessel reactors are restricted in their ability to adapt to changing conditions and require a lot of maintenance.

3.6 Weed, Pest, and Disease Management in crops

To control weeds, pests, and disease, chemical herbicides, fungicides, insecticides, and pesticides are frequently utilized. However, public awareness of pesticide exposure in rural areas and pesticide residues on food has grown. For large agricultural watersheds, pesticide pollution of the nation's surface and ground water supplies is already extensively established. The effects of some pesticides on animals are becoming more understood, and nonlethal effects produced by pesticides, such as disruption of diverse creatures' endocrine systems, are becoming more well-known.

The farmer must control weeds, bugs, and diseases that wreak havoc on his crops. Controlling the process will guarantee that the yield is not lowered. The following are the two major ways of control [5].

Cultural Control

This has developed from conventional farming practices. Culture control is preventative, but it needs long-term preparation. The following are some examples of cultural means:

- Ploughing Burys perennial weeds, allowing them to die and degrade.

- Sow when the annual weeds are dormant seeds and the perennial weeds have been ploughed.
- Weeds must be eliminated at a critical point in the crop's life cycle — removing weeds early in the crop's life cycle causes the crop to grow stronger.
- Alternative hosts of pests can be weeds near the border of fields, and eradicating these pests is a good way to control them. This, however, may have a negative impact on animals.
- Crop residue destruction - disease spores can live on leftover straw or stubble after harvest.
- Cover crops are weed-controlling crops that are planted on fallow ground.
- Crop rotation is the practice of growing a variety of crops on the same piece of land over time. Pests in the current crop will not be present in the next harvest.

Chemical Control

Farmers will also employ chemical measures to boost agricultural yields, as traditional methods are insufficient.

Pesticides like these can be used by farmers:

- Herbicides for weed killers.
- Fungicides to kill fungal parasites.
- Molluscicides are pesticides that are used to kill molluscs.
- Nematicides to kill nematode pests.

These compounds have different effects depending on whether they are selective or systemic [25].

Systemic insecticides, molluscicides and nematicides spread through the vascular system of the plants and kill pests that are feeding on the plants.

Types of herbicides	How the herbicide acts
Selective herbicide	Certain plant species, such as broad-leaved weeds, are more susceptible. They're made to look like plant growth hormones. As a result, they boost weed growth and metabolism. This occurs until the point when the weeds' food source is depleted, and they die. Crop plants only absorb a little amount of the chemical. Selective herbicides are biodegradable and have no negative effects on the environment.
Systemic herbicide	Herbicides that penetrate the vascular system of weeds are known as systemic herbicides. The chemical is delivered to all sections of the weed, resulting in its death. Herbicides used systemically penetrate subterranean organs and roots, killing them and inhibiting regeneration.

Table 3.7: Types of herbicides and it's act

Chapter 4

Vertical Farms

4.1 Difference between Green House and Vertical Farms

Although the two technologies are sometimes mistaken, they differ significantly in terms of resource usage, cost, production, and, probably most crucially, the best sites for each. Greenhouses are a more conventional technique with which you're probably already familiar: A single layer of crops grown inside an enclosed room with glass or plastic walls and a roof to allow natural light to enter. It's a semi-controlled situation [26].

Vertical farms, on the other hand is exactly what it sounds like: farming that takes place on vertical surfaces rather than horizontal ones. Farmers can produce a lot more food on the same area of land by employing vertically stacked layers. These layers are frequently incorporated into structures such as skyscrapers, warehouses or shipping containers, greenhouses, or other locations that would otherwise be unsuitable for farming.

However, vertical farming entails considerably more than simply stacking plants and hoping for the best. To be successful, the technique necessitates the manipulation of temperature, light, and humidity. It's possible to lose a whole harvest if a delicate balance is not maintained, much as a traditional crop could in the event of a drought or flood [27].

4.2 Types of Vertical Farming system

Vertical farms exist in a variety of shapes and sizes, ranging from modest two-level or wall-mounted systems to multi-story warehouses. However, all vertical farms employ one of three soil-free nutrient delivery technologies.

These three growth systems are described in the following way:

- Hydroponics
- Aeroponics
- Aquaponics

4.2.1 Hydroponics

Hydroponics is an alternative to traditional agriculture, in which plants are grown in soil and rely on the earth for moisture, nutrients, and support. Hydroponics is the remarkable capacity to grow plants using just water and a liquid nutrition solution. A reservoir holds both the water and the nutrition solution. It's genuinely remarkable, and it's growing in popularity among both commercial and domestic producers.

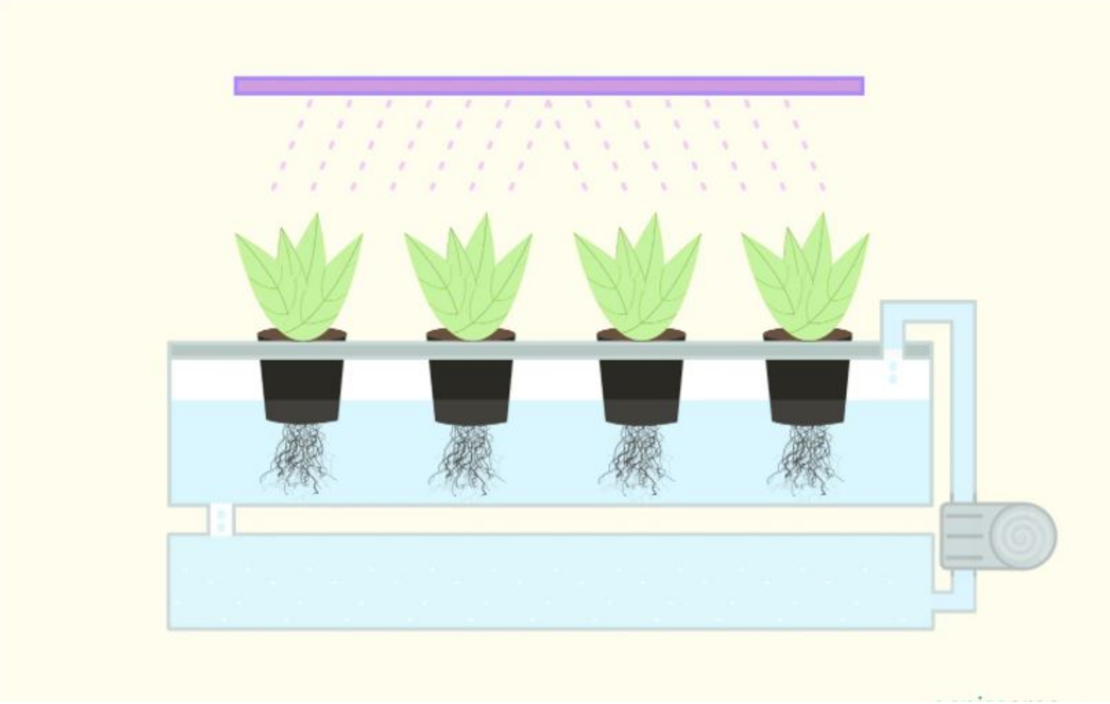


Figure 4.1: Hydroponic system.

On the industrial side, hydroponics offers significant benefits, and it has been a major priority for more sophisticated societies [28].

Types of hydroponics systems

The other main hydroponics systems, besides aeroponics, are:

- DWC (deep water culture)
- Wicks
- NFT (nutrient film technique)
- Ebb and flow
- Drips

Some of the systems I've listed above, for example, can be converted to function as aquaponics systems. By adding fish to the tank/reservoir, the DWC, NFT, and ebb and flow may be converted into aquaponics systems [28].

Hydroponic Components

- Growing medium serves as a buffer for the plants as well as a means of stabilizing them. In order for plants to grow healthy, they must have particular traits. Rockwool expanded clay pellets, coconut fiber, Growstones, and oasis cubes are among the most successful and widely used media.
- Reservoir where the fertilizer solution is held in the, which is the foundation of any hydroponic system.
- Submersible pumps to transport nutrient solution-dissolved water from the reservoir to the growth chamber/root zone, allowing the plants convenient access.
- Fertilizers, Organic fertilizers consisting of plant or animal-derived materials or by-products of natural processes are utilized in hydroponics, whereas inorganic fertilizers comprised of minerals and synthetic compounds are frequently manufactured from natural resource materials.
- Air Pumps, Plants need oxygen to thrive, and in certain hydroponics systems, they can "drown" if they don't have enough.
- Pipes are an important feature of hydroponics systems because they connect the nutrient reservoir to the plant-growing trays [28].

commercial benefits

- Water use is reduced (as much as 10 times less water than soil crops).
- Better plant density, higher yields.
- A far more environmentally friendly option.
- Herbicides aren't required.
- Because the growth chambers are shut off, insecticides aren't needed as much.
- A viable alternative in areas where the soil has been damaged.
- Hydroponics is viewed as the answer to feeding the world's ever-growing population.
- When compared to soil crops, plants can develop 40-50 percent quicker and generate 30 percent more yield [28].

Hydroponic Disadvantages

- Expensive to set up.
- Vulnerable to power outages.
- Requires constant monitoring and maintenance.
- Waterborne diseases.
- Problems affect plants quicker [29].

4.2.2 Aeroponics

Aeroponics is described as "growing plants in an air/mist environment with no soil and very little water" and was coined by NASA in the 1990s as an attempt to develop efficient ways to grow plants in space. The National Aeronautical and Space Administration (NASA) is in charge of creating this ground-breaking indoor growth method. Aeroponics systems are still a rarity in the field of vertical farming, but they are getting a lot of attention. Aeroponic systems use up to 90% less water than even the most efficient hydroponic systems, making them the most efficient plant-growing technology for vertical farms. Plants produced in these aeroponic systems have also been found to absorb more minerals and vitamins, perhaps making them healthier and more nutritious [30].

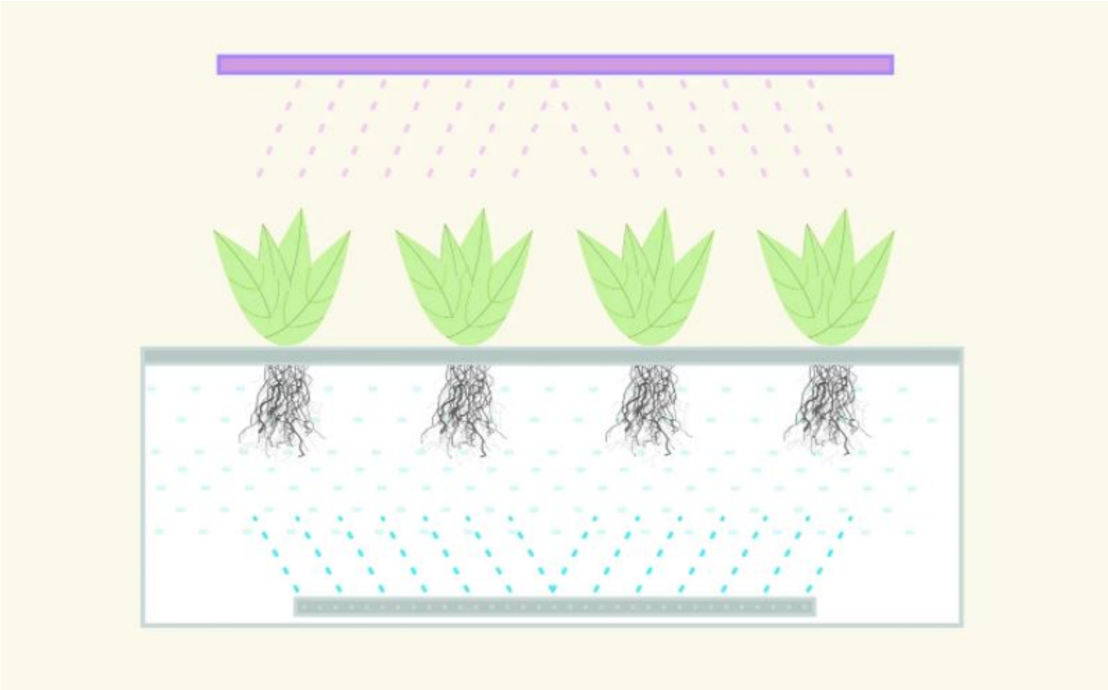


Figure 4.2: Aeroponic system.

Aeroponics components

- Water and fertiliser solution are stored in a reservoir.
- There is no waste since the additional water and nutrients that are not utilised by the roots are returned to the reservoir.
- Plant roots are suspended in the air using net cups.
- Pumping water via the misting nozzles with a water pump.
- The water pump is activated by a timer.
- It's called a repeat cycle timer or a recycling timer — growers may play about with the schedule; some set it for 1 minute on and 5 minutes off, while others advocate 5-10 seconds of mist every 3-5 minutes.
- Lights for growing plants [28].

Aeroponics benefits

Aeroponics has the ability to:

Reduce water use by 98 percent, fertilizer consumption by 60 percent, and pesticide usage by 100 percent.

It can achieve all of this while still increasing crop yields [28].

Aeroponics disadvantages

- Since there is no growth media (air is the growing medium), pH levels and nutrient density ratio must be constantly monitored.

- No room for power interruptions - commercial growers require a backup power source.

- Costly to set up and requires technical expertise.

- Root chamber cleaning is required on a regular basis.

- Can be loud in small spaces [28].

4.2.3 Aquaponics

A system expands on the hydroponic system by incorporating plants and fish into one environment. Fish are raised in indoor ponds, creating nutrient-rich excrement that is utilized to feed the vertical farm's plants. The plants then filter and cleanse the wastewater before returning it to the fishponds. Although aquaponics is employed in small-scale vertical farming systems, most commercial vertical farming systems only produce a few fast-growing vegetable crops and do not contain an aquaponics component. This reduces the complexity of economic and manufacturing challenges while increasing efficiency. New standardized aquaponic systems, on the other hand, may serve to increase the popularity of this closed-cycle system [30].

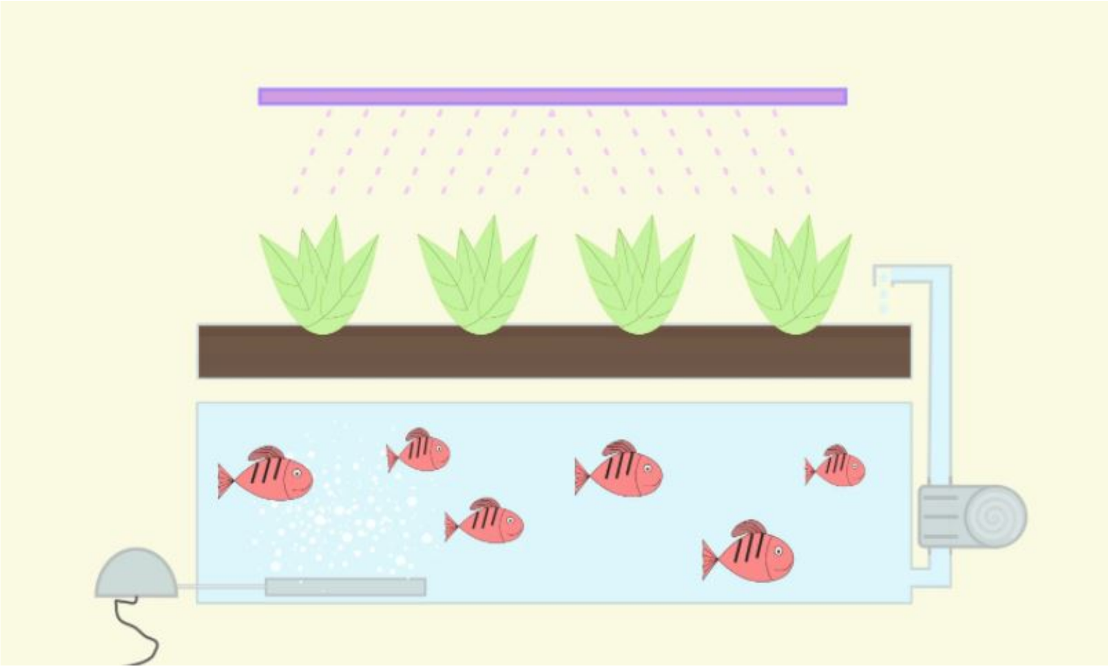


Figure 4.3: Aquaponic system.

Aquaponics components

- acquarium, obviously there are fish
- The most common fish used in aquaponics is tilapia, however other species such as trout, carp, channel catfish, largemouth and striped bass, Arctic char, and goldfish can also be utilized.
- Plants are housed in a grow bed with net pots (like it happens with the nutrient film technique system).
- The ideal grow media for aquaponics (hydroton, gravel, lava rocks, growstones) differs from those for hydroponics; expanded clay aggregate and gravel are the two most prevalent ones.
- Styrofoam rafts and net pots floating in wastewater may be used to replace the grow bed with net pots and growth media (similar to a deep-water culture system but with fish).
- A water pump is used to distribute water to the grow bed.
- Tubing is used for both pumping up the water and returning surplus water from the grow bed to the reservoir and the fish.

- For the fish, an air pump is used to circulate oxygen.
- Lights for growing plants.
- If you want to create your own aquaponics system, there are lots of YouTube tutorials available to help you.
- You'll also need a timer if you're installing an ebb and flow aquaponics system [28].

Aquaponics benefits

- Those interested in cultivating both fish and plants at the same time have identified the ideal system for them in this hydroponics vs aquaponics vs aeroponics discussion.
- The water is returned to the tank in a recirculating ecology.
- Chemical fertilizers aren't required.
- The nutrients from the wastewater are continuously given to the plants, eliminating the need to top off the nutrient solution, as in hydroponics and aeroponics, resulting in no additional costs.
- Environmentally friendly and sustainable.
- The ideal combination of hydroponics and aquaculture.
- Compared to aquaculture, it uses less water.
- Plants grow quickly [28].

Aquaponics disadvantages

- In the winter, the system must be housed in a warm area to prevent the water from freezing, which might result in increased heating costs.
- expertise in the handling of fish.
- Even in aquaponics, the pH of the water must be monitored - a suggested pH range for fish, plants, and nitrifying bacteria is between 6.4 and 7.4; in hydroponics and aeroponics, the pH range is between 5.5 and 6.5. (5.8 to 6.0 on industrial scale).
- Supplementing calcium, potassium, and iron may be necessary [28].

4.3 Nurseries and System for growing seedling

Plant nurseries have long been used in traditional farming to promote crop uniformity, reduce the growing season, and boost crop yields. Plant nurseries are frequently used by vertical farms to start seeds. Seeds are often sown in Rockwool plugs, irrigated, and then placed in nursery rooms with LED grow lights and climatic settings customized to the seeds' requirements. When the roots of the seedlings reach the bottom of the Rockwool plugs, they are moved to the vertical racks.

Furthermore, nurseries in vertical systems allow producers to more correctly estimate the harvest date of their crops and dynamically utilize space. When compared to producing leafy greens like butterhead lettuce in the sun, growing them in nurseries with LED lights improves plant weight by roughly 56 grams. Vertical farms may also grow more than one sort of crop at a time thanks to nurseries. However, transferring crops from plant nurseries into primary growing systems has certain drawbacks, including higher labor costs and the possibility of transplant shock, which can stymie plant development. Furthermore, it has been noted that plant roots frequently stick to the growth media, causing root system injury [31].

4.4 How does vertical farming technology work?

Vertical farming is a growing trend in which crops are grown vertically rather than horizontally. The production of crops in controlled surroundings, where every aspect affecting their growth is continuously monitored and adjusted to their demands, is what a vertical system is all about.

Vertical farming is based on the notion of controlled environment agriculture, in which cutting-edge technology are used to create optimal conditions for any crop. Vertical farming is ready to reach new heights thanks to emerging technologies like artificial intelligence (AI), machine learning (ML), and the Internet of Things (IOT). Understanding the technology that enable it is the most effective way to describe it. We'll look at how controlled environment agriculture works, how different parameters are regulated, and how emerging technologies like AI, ML, and the IOT are driving innovation in indoor crop production in the sections below.

4.4.1 Controlled Environment Agriculture

Because it incorporates multiple technologies to offer plants with the optimal environmental and development circumstances during their growth, controlled environment agriculture is basically at the heart of vertical farming. Vertical farming can grow fresh, pest-free crops all year round by adopting a controlled environment system. Plants are insulated from the outside environment in vertical farms, and staff take precautions to avoid insect infestations that may harm the crops. Controlled environment systems are often associated with vertical farming, although they may also be employed in horizontal farming.

Temperature, carbon dioxide, oxygen, lighting, humidity, nutrient content, pH, insect management, watering, and harvesting are all monitored using smart sensors in vertical farms. Hydroponic, aeroponic, and aquaponic are common in controlled conditions. Furthermore, modern image and sensor technologies such as cameras and thermal imaging may be used in controlled environment agriculture to monitor plant growth, temperature, and other parameters. Controlled environment systems have shown to be particularly effective in growing leafy greens, herbs, microgreens, and crops including tomatoes, peppers, melons, and sweet corn in the past.

4.4.2 Controlled Environment Component

Heat System

The place of plant growth is governed by temperature. Chemical reactions tend to speed up as temperatures rise. The majority of chemical reactions in plants are governed by enzymes, which function best within specific temperature ranges. Enzyme activity begins to decline above and below certain temperature ranges, and chemical activities halt or cease as a result. Plants get stressed at this moment, their growth slows, and they may finally perish. For a quick and successful maturation, the temperature of the plant environment should be regulated at optimal values. The temperature of both the air and the water must be monitored and managed [32].

Dosing System

The use of an automated-dosing system to provide nutrients to the plants and monitor the nutrient solution is a typical strategy in vertical farming. Automatic-dosing systems monitor nutrient contents, Potential Hydrogen (PH) and Electrical conductivity (EC) levels, and water temperature in the reservoir on a continual basis. Peristaltic pumps suck the needed amount of nutrients and disburse them into the reservoir link the dosing system to the nutrient supply in most cases. In the reservoir, probes assess pH and EC in real time, and if necessary, the dosing cycle is restarted. Growers can have better control over the nutrient solution using an automated dosing system since they don't have to spend as much time adjusting pH, EC, nutrients, and temperatures. Plants are also given a correct amount of nutrients, which prevents plant shock and stunted development, which are common outcomes of unbalanced growing circumstances.

Figure 4.4: Dosing system for vertical farms

Sterilization Systems

Sanitation is required for plant development to be optimal and for international food safety criteria to be met. Vertical farming employs stringent sanitation and disinfection procedures to maintain pesticide-free crop production all year. Chemical disinfection, UV-C sterilization, and ozone sanitation are the most often utilized procedures for sterilization [31].

Chemical Disinfection and Sanitizing

Surfaces like flooring, moving equipment, and instruments like harvesting clippers may readily transfer illnesses from plant to plant if not sterilized using chemicals like hypochlorite and hydrogen peroxide. Cleaning eliminates pollutants, dirt, and germs from things or surfaces, according to the Center for Disease Control (CDC). Pathogens on any given surface are reduced to an acceptable level through sanitizing, as defined by public health regulations. To effectively sterilize, the solution must decrease bacteria by 99.9% within a 30-second time frame. Disinfecting, on the other hand, necessitates a 99.999% decrease of these germs in a five-to-ten-minute period. This effectively eliminates the germs. Although the difference between 99.9% and 99.999 percent may appear little, surfaces contain millions of bacteria. Infection may be disseminated swiftly with just a few minute particles. So, Cleaning removes dirt and debris from surfaces, sanitizing reduces germ counts (by 99.9%), and disinfection destroys germs completely (99.999%) [33].

Ultra Violet Sterilization

Sterilization using UV emitting lights is a chemical-free method of killing bacteria, fungus, and viruses, among other microbes. Because it destroys 99.9% of all germs in the treated area, this is one of the most successful sterilizing treatments. UV-C sterilization is most typically used in vertical farms [33].

UVA, UVB, and UVC are the three forms of ultraviolet light. UVC is used in hospitals, airlines, offices, and industries to sterilize them. UV sterilization employs UV radiation (wavelengths of 100–400 nanometers) outside of the visible light spectrum (wavelengths of 400–800 nanometers) to break and destroy DNA, rendering contaminants incapable of performing their biological activities.

Because certain molds demand 50 times more UV light than bacteria, proper dosage is critical, and employing a low dose of UV light leaves some gardeners unhappy with the outcomes. UV sterilization can also cause color change and terpene loss in your plants due to oxidation. As you continue, test for any flaws so you can address them before they get more serious and out of hand [31].

Ozone Sanitation

The ozone gas, which is found in abundance in the environment and on the ground, is used to clean the air in indoor farms in this approach. Fungi and bacteria have been shown to be killed by high quantities of ozone gas. Ozone gas, when used in high concentrations, may be an excellent sterilizing agent.

Ozone exposure levels of 0.2 ppm are recommended by the National Institute for Occupational Safety and Health (NIOSH). Ozone levels of 5 parts per million (ppm) or above are deemed life-threatening. Workers must not be exposed to an average concentration of more than 0.10 ppm for more than 8 hours, according to the Occupational Safety and Health Administration (OSHA). While ozone is a powerful air purifier, there are additional items that may help you sterilize the hard-to-reach parts of surfaces and equipment [33].

Recapturing Water from Moist

The typical vertical farm consumes 95 percent less water than horizontal farms when using hydroponic, aeroponic, and aquaponic growth methods. Furthermore, many vertical farms save water by recapturing and reusing irrigation water. During the process of transpiration, plants lose most of the water they are given, and some vertical farms capture this water using dehumidifiers and air conditioning. The collected water is reused in the manufacturing process once it has been filtered and treated [31].

A reservoir that stores the water-nutrient solution and a growth tray that retains the plants are the two major components of a hydroponic system. Crops are grown in pots containing organic elements like perlite, coconut coir, Rockwool, Growstones, or expanded clay pellets, which offer physical support to the root system. Nitrogen, potassium, phosphorus, calcium, iron, manganese, zinc, and chlorine are all dissolved in water and given to the roots immediately. Plants are usually hanging in the air above the water reservoir, with their roots partially or completely immersed [34].

Lighting

Natural light is replaced with artificial lighting in indoor farming, which acts as the crop's sole source of illumination. Plant development and yield are influenced by the color, intensity, and duration of light. Because each stage of plant development has varied lighting needs, vertical farming requires a lot of study to find the best performing light source. Fluorescent grow lights, high-pressure sodium lights (HPS), and LED lights are the three types of grow lights now used in indoor agriculture [31].

- Flurescent grow lights: Vertical farming is commonly used to cultivate leafy greens and vegetables. Tubular grow lights and compact fluorescent lights are two types of lights that are created by transmitting energy via a gas in a tube. Fluorescent lights come in a variety of shapes, sizes, and intensities, as well as a spectrum of color temperatures ranging from 2,700K to 10,000K. Furthermore, they are available in narrow designs that allow them to fit into tighter locations, and they have a long light life of between 12,000 and 20,000 hours. Regardless, fluorescent lights are costly to maintain, need a ballast, contain mercury, and lose efficiency with time. Compact fluorescent lights (CFLs), unlike regular fluorescent lights, emit less heat, are more efficient, and do not require a ballast to operate. These lights, which are specifically built for indoor farming, are also the most affordable of the three primary lighting sources used in vertical farming. Despite this, CFLs have a low light intensity, which has an impact on plant development. They also contain trace levels of mercury and deteriorate in quality with time.

- HPS-high pressure sodium lights: In the 1950s, sodium lights, sometimes known as HPS lights, were created for street lighting. It's a kind of gas discharge light (HID). An HPS lamp is made up of an aluminum oxide arc tube holding sodium, mercury, and xenon, according to The Edison Tech Center. HPS grow lights are particularly popular in vertical farming since they generate predominantly Red (45%) and Green (52%) light, which are both necessary for blooming and fruiting. HPS grow lights, on the other hand, lack blue light (3%) and hence may limit plant growth during the early stages of development, resulting in low yields. HPS lights also produce a lot of heat, contain mercury, and have a low color rendering index of 24, making visual monitoring of the plants difficult.

- Led lighting: NASA was the first to use LEDs for growing indoor plants, and they are quickly becoming the preferred illumination for many vertical farms around the world. When an electric current runs through a semiconductor, the semiconductor generates light through the electroluminescence process. Indoors, LED lights are used to cultivate a variety of crops, including leafy greens, tomatoes, and herbs. LED lights are widely used in vertical farming for a variety of reasons. For starters, LED grow lights produce less heat than HPS grow lights, allowing producers to position them closer to their crops and save space. Second, they have a lengthy life span since they seldom fail, although their brilliance fades with time. LED lights have the benefit of using 85 percent less energy than standard incandescent bulbs, lowering energy-related expenditures in vertical farming [31].

Air Control

There are 6 techniques could be used for the air control. Here it's:

- CO2 enrichment: The optimal CO2 concentration for indoor farming is roughly 1000 parts per million, however during ventilation and photosynthesis, these levels can easily fall below 800 parts per million. Carbon dioxide is an essential component of photosynthesis, and even little changes in its concentration have a direct impact on plant growth and production. CO2 enrichment has been shown to stimulate fast plant development and boost plant production. CO2 enrichment techniques range from classic low-tech to high-tech sensor-based technologies.

- CO2 Gassing: By utilizing carbon dioxide burners to burn propane or natural gas, this traditional method creates CO2. CO2 airflow is controlled by HVAC systems, which ensures that the gas is distributed evenly throughout the growth space.

- Compressed CO2: This method entails converting compressed CO2 from a liquid to a gas and then introducing the gas into the growth chamber over a period. A pressure regulator is used to lower the gas pressure.

- Misting aqueous CO2 by CO2 delivery solutions: It is one of the most advanced and cost-effective CO2 enrichment technologies since CO2 is delivered directly to plant leaves. In a CO2 infusion system, CO2 is injected, which dissolves the gas and saturates the water. After the CO2 solution has been saturated, it is misted directly onto the plant's leaves as microdroplets using an overhead misting system. Because it does not require extra equipment such as HVAC systems, the technology decreases the quantity of CO2 utilized and the additional expenditures associated with CO2 enrichment.

- Air flow: A vertical farm must have steady airflow in order for plants to develop correctly. Vertical systems use airflow to transport air via filtration devices, reducing humidity, removing heat, and circulating CO2. Heat and humidity build up in the growing area, making it an ideal breeding ground for bacteria, fungus, and mold, increasing the risk of illness. The layout of an indoor farm is also important for air circulation throughout the facility. Vertical farming methods, for example, employ vertical planes to allow air to travel more freely than horizontal agricultural systems. Various airflow monitoring devices have also been created. This system employs airflow transducers at the farm's entry and exit points to monitor air velocity 24 hours a day, seven days a week using a hot-wire system that sends the data to a terminal. This allows producers to respond in real time if airflow in a vertical farm is too low or too high.

- Air humidity: Humidity is an important consideration for growing plants indoors since it reflects the quantity of water vapor in the air. Most crops grow when humidity levels are between 40% and 50%, and they suffer when humidity levels change. Low humidity stunts plant development and lowers produce quality, whereas excessive humidity causes bolting, lower yields, and worse quality. If not addressed quickly, a high amount of humidity can lead to fungal development, which can result in full crop loss. When plants transpire, water vapor is generated, which can build up in the growing environment of indoor farms, causing increased humidity. Dehumidifiers and dehumidification systems are used by vertical farms to keep their humidity levels in check. To manage relative humidity and dew point, dehumidification devices remove surplus moisture from the growth environment. Furthermore, Dutch scientists devised a dehumidification mechanism that prevents excessive evaporation into the atmosphere. Vertical farms may save around 10% more water than regular growing by recycling their own water and natural humidity [31].

The Internet of Things IOT

In the agriculture, IoT is already being utilized to increase production, monitor crops at all times, and improve farming efficiency. Vertical farming uses IoT to regulate the growing environment in which crops are grown, as smart sensors detect everything from humidity to pH levels and relay the information to producers in real time.

- Sensors: are the backbone of IoT because they monitor physical input like heat, light, humidity, and so on, convert it to data, and transfer it to the screen, where it is interpreted by either machines or people. In vertical farms, a comprehensive network of IoT sensors is employed, including CO2 sensors to monitor and maintain appropriate CO2 levels, particularly in the growth chamber, and temperature sensors to assess light intensity and outside temperature. Humidity sensors, pH sensors, EC sensors, magnetometer sensors, air quality sensors, and other sensors are also used.

- Image Processing for evaluating plants health and maturity: Vertical farms also utilize image processing software and sensors to monitor the health and growth of their crops. These programs are used to detect developmental abnormalities, monitor insect damage, and assess the amount of macroelements like nitrogen. For example, "Agricola Moderna," an Italian vertical farm, was able to extract important information regarding the presence of macroelements such as nitrogen and phosphorus in its crops using hyperspectral photography. These macroelements are excellent predictors of plant health in plants. Data acquired by in-situ sensors is sent in real-time to a central computer, where it is analyzed using artificial intelligence and machine learning. Growers can now make the most of their data, detect patterns, and fix issues in real time [31].

Vertical Layout of Farms

Horizontal indoor farming, unlike outside agriculture, includes growing crops in rows. This sort of setup, which is commonly found in greenhouses, takes up a lot of room. Vertical systems, on the other hand, plant crops in vertical tubes and stack them on top of each other using vertical racks. Farmers may produce more crops in a smaller space by growing plants vertically, allowing them to utilize available space and enhance output per square foot of land. Furthermore, numerous technology businesses are promoting vertical farming innovation by developing racks that consume less space and maximize area.

Vertical farms use hydroponic, aquaponic, and aeroponic processes as an alternative to soil-based growth methods used in horizontal farming. Growing medium such as clay pellets, perlite, coconut coir, Rockwool, and oasis cubes give physical support to plants. Water and nutrients are delivered directly to the roots of the plants using an efficient system of pipelines, tubes, and pumps. Additionally, this system collects extra water and recirculates it to the plants. Aquaponics, which combines hydroponics with aquaculture to create fresh plants and fish as shown in figure 4.5, is another growth technology used in vertical systems. Plants are grown in growth media and fed water and nutrients from the fish tank in this approach. Fish waste is broken down by microorganisms and dissolved into important plant nutrients like nitrogen and phosphorus, therefore this system does not require fertilizers [31].

Figure 4.5: Aquaponic wattering technique [31].

4.5 Advantages and Disadvantages of vertical Farm

Vertical farming has the potential to be a very promising future food source since it can efficiently use space to grow vast quantities of vegetables and fruits. However, in addition to a slew of other benefits, vertical farming has a number of drawbacks [35].

Vertical farming pros

- Crop yields that are consistent
- Protection from the elements outside
- Maximization of profits
- Pesticides cause less crop losses
- Protection from wild animals
- Savings on water
- Imports of less crops are required
- Land use efficiency
- There will be less habitat damage
- Yields all year long

Vertical farming Cons

- Expertise was required to set up the systems
- High start-up expenses
- Maintenance charges are high
- Energy expenses are high
- Technology isn't quite there yet
- Labor costs are quite high
- Problems with pollination
- Official approval is required

- High-skilled personnel are required
- People in rural locations face a variety of issues

Chapter 5

Traditional Lettuce Cultivation

Lettuce is a cool-weather crop that thrives at temperatures between 60 and 65 degrees Fahrenheit, and most kinds can withstand temperatures as low as 20 degrees Fahrenheit if properly hardened. Cold-tolerant cultivars may withstand significantly lower temperatures. Around 75 degrees F is ideal for seed germination. Lettuce seed germinates in temperatures as low as 40 degrees Fahrenheit. Hardened transplants from seed grown one month before placing outside should be used for early spring plantings. Direct seeding can be used for later plants. Depending on the cultivar, sow seed 1/4 deep and thin to 10-16 apart. Planting loose-leaf cultivars closer together is possible, but excellent air circulation around the plants should be maintained. During the germination stage, the soil should be cold and wet. It's a terrific leafy green to grow since it grows rapidly, produces for a long time, and requires little maintenance as long as you keep it well watered.

In germination phase, when the temperature rises over 80 degrees Fahrenheit, lettuce is less likely to germinate. Lettuce seeds may be sprouted in the refrigerator for 4-6 days and planted in the late summer or early fall when the days are still hot. Another way is to soak the seed in 10% bleach for 2 hours at 40-60 degrees F, then rinse it four times with water. This approach improves germination speed and quantity. Another option is to cover the soil with burlap or boards to keep it cool; remove the cover as soon as the seedlings emerge to keep grasshoppers and other pests away.

In order to get good result in this traditional cultivation there are specific requirements so it will be discussed bellow step by step.

5.1 Lettuce Soil Requirements

Lettuce grows best in well-drained, nutrient-rich soil. Before sowing seeds or transplanting young seedlings, it is critical to do adequate field preparation. One week before transplanting or direct sowing, experienced farmers recommend tilling the soil and applying compost or well-rotted manure. Lettuce loves soil that is rich and has a pH of 6 to 6.8 in most circumstances. Farmers like to maintain the soil moist all of the time to ensure healthy plants and high harvests. Before planting, growers are required to do a soil test. To establish a sensible field preparation strategy, it is advised that you speak with a local professional agronomic [36].

5.2 Lettuce Water Requirements

The root system of lettuce plants is rather shallow. Smaller, more frequent watering sessions are usually preferred by them. We may need to irrigate lettuce plants every day during the hot summer months, and we may need to shade them. Lettuce plants will suffer from heat if we don't irrigate them on a regular basis this season, and bolting will be a problem, the plant starts to produce seeds. As a result, bitterness may develop in lettuce leaves. Bolting is usually irreversible, and plants that have bolted are unable to be sold. Sprinkler and drip irrigation technologies are used by the majority of farms. Farmers may spread a thin layer of mulch on the ground to keep the soil wet at all times. The plant's growth will be hampered by sudden changes in soil moisture.

For the majority of its growing span, lettuce should be watered roughly twice a week, or once every four or five days. For the first two weeks following planting, it will need to be watered softly but more regularly, maybe daily, depending on your environment. Water lettuce to a depth of six inches twice a week for the duration of the growth season.

If you're not sure if your lettuce plants need to be watered, insert your finger about an inch into the earth near where they're growing to test the moisture level of the soil. The ground is still damp and plants do not need to be watered if it feels moist to the touch and the dirt adheres to your fingertips.

Watering lettuce plants early in the morning or late in the afternoon is highly recommended. It's critical to prevent over watering, which can lead to disease outbreaks and root rot. The key to cultivating good lettuce is to keep the soil wet [36].

5.3 Lettuce Planting and Spacing – Seeding rate and Planting Distances

Lettuce plants, in general, require moderate conditions to grow. Depending on when we want to harvest the seeds, we should plant them in the right time frame. Lettuce can grow in temperatures ranging from 45 to 64 °F (7-18 °C) depending on the type. Lettuce may grow at temperatures as low as 84 degrees Fahrenheit (29 degrees Celsius) in particular conditions and with extra care for example, shade. When it comes to planting lettuce in the spring or fall, a sunny spot is ideal. On the other hand, if we opt to grow lettuce in the late summer, it will require adequate sun protection. Shades can be used to achieve this. When the weather begins to cool, we may remove the blinds and allow the young plants to get the necessary sunshine.

Plants can be straight seeded or transplanted. In direct sowing, lettuce seeds are planted in rows at a depth of 14 inches (0,6 cm). We can also sow by spreading seeds for a wide row planting. Experienced farmers report that spring frosts and summer heat harm their plants in the majority of situations. They generally start growing their plants inside to avoid this. Before the first frost, growers usually begin sowing indoors. They can transfer them outdoors two weeks after the last frost. The dirt block is affixed to the lettuce plant when it is transplanted. Farmers might use the same strategy to combat summer heat. They grow lettuce seeds indoors during the hot summer months. Then, when the weather cools, they generally move them outside.

Farmers may take into account the following aspects in order to achieve optimum growth and optimize their harvests.

- Seeding Rate: Per hectare, 800-1000 gr (28–35 oz.) of seeds
- Plant density per hectare: 50.000-60.000 plants knowing that 1 hectare = 247 acres = 10.000 square meters
- The distance between rows should be 11-23 inches (27-60 cm), while the distance between plants should be 7-12 inches (18-30 cm)
- Lettuce seeds are tiny and need to be planted at a depth of 14 inches (0,6 cm)
- Once the seeds have germinated, we may thin them out. We can keep trimming lettuce heads until there is enough space between them. A usual pattern is to space each plant at least 7 inches (18 cm) apart, however this varies according on the type.

- Other plants may be planted between lettuce fields by farmers (inter-cropping). Garlic rows can help manage aphids, while sweet corn or peas can give natural shade.

- Farmers may arrange a good growing plan by consulting a qualified agronomic in their area [36].

5.4 Lettuce Fertilizer Requirements

Before applying fertilizer, it's critical to do a soil study. No two fields are alike, and no one can provide you fertilizer recommendations without first learning about your crop history and the findings of your soil study. Because lettuce matures quickly, many growers just apply a single fertilizer treatment approximately 20 days after transplanting. In other circumstances, the lettuce crop is created as a rotation crop between heavy feeders (for example, broccoli), in which case no fertilizer is applied. However, illnesses may be an issue with this procedure.

Fertilizer is usually applied three weeks after the plants have been transplanted into their ultimate location. Farmers let the lettuce grow in height before fertilizing it in several types. Many farmers employ a well-balanced fertilizer, generally in the form of granules, that contains critical elements including nitrogen (N), potassium (K), and phosphorus (P). Granular fertilizers can be administered in 10-10-10 (N-P-K) or 5-5-5 (N-P-K) mixes, according to experienced farmers. The granules can be sprinkled on the ground around lettuce plants. It is critical that the granules do not come into contact with the young plants, since this might cause them to burn. Irrigation is frequently necessary after fertilizer application.

In certain circumstances, farmers choose fertilization, which involves injecting water-soluble nutrients into a drip irrigation system. Before injecting any water-soluble fertilizer, it is recommended that we follow the manufacturer's recommendations.

Finally, approximately 35 days after transplanting, some farmers spray $KNO3$ at a rate of 200 kg per hectare (1 hectare = 2,47 acres = 10.000 square meters, and 1 ton = 1000 kg = 2200 lbs.).

Two weeks before planting, organic farmers can apply well-rotted manure and plow the soil. Weed control and soil moisture conservation are both aided by organic manure. These are, however, frequent patterns that should not be followed without more investigation. Every field is unique and has its own set of requirements. After doing a soil test, you can seek guidance from a qualified agronomic [36].

5.5 Lettuce Pests and Diseases

To combat our agricultural adversaries, we must first learn about them and develop an environmentally friendly strategy ahead of time. For appropriate management of lettuce pests and diseases, we can consult a local qualified specialist. Below is a list of the most prevalent lettuce pests and illnesses.

5.5.1 Pests

Farmers must maintain control and check crops to prevent pests such as;

Aphids

They are one of the most frequent pests that attack leafy greens. Adults and nymphs eat plant fluids, as well as stems, flowers, and leaves. Reduced growth rates, mottled leaves, yellowing, stunted growth, curled leaves, browning, wilting, reduced yields, and, finally, mortality are all signs of aphid damage. Aphids may spread infections as well as stealing plant fluids through direct eating.

Figure 5.1: Lettuce infected by aphids.

Slugs

Slugs prefer crunching the lettuce leaves, resulting in huge holes and items that can't be sold. If they are allowed to proliferate freely, they have the potential to wipe out the whole crop in a short period of time. Slugs (and snails) gnaw holes in leaves and fruits with smooth edges, and young seedlings can be completely swallowed. Slug and snail eating is at its peak at night or during wet months.

5.5.2 Diseases

Because of farmer's negligence, crops can infect some diseases such as;

White Mold

It's a fungal infection called sclerotenia. It has an impact on a wide range of plant species, including lettuce. The stems can be used to identify it. The stems look to be withered and browned. The beans become inedible when the pod tissues deteriorate due to this illness. Plants should be able to continue to grow normally. This illness causes the beans within the pods to decay.

Bottom Rot

It's a fungus that primarily affects older plants. Rhizoctonia solani is the cause.

Downy Mildew

Bremia lactucae causes yellow necrotic patches on older leaves, which is caused by the disease. Brown spots on lettuce leaves are unappealing and should be avoided. Infected plants' inner leaves are frequently spared from infection.

Figure 5.2: Lettuce infected downy mildew disease.

Leaf Drop

Plants grow normally until a few days following a spell of chilly rain, which has resulted in extremely saturated soil. The outer leaves begin to wilt first. On the undersides of the wilted patches, a soft cottony mold develops. Plants look to have partially collapsed at this time and may have a rotten odor. Because the fungus have infiltrated their circulatory systems and caused them to rot from within, severely damaged plants are inedible. Plants flop over and die as the illness spreads.

Figure 5.3: Lettuce infected by leaf drop disease.

Mosaic Virus

The leaves of immature plants get twisted and partially folded as they expand. When mature plants become infected, older leaves have mottled regions of yellow and green, and huge leaves near the head may become twisted. New growth is skewed and sluggish. The lettuce mosaic virus, like other plant viruses, disrupts genetic signals inside the plant. Plants that have their leaves warped by the virus are unable to function correctly, so they struggle to develop and eventually cease growing.

5.6 Pest and Disease Control

Rather of intervening, the greatest strategy to control pests and illnesses is to avoid them. The following steps should be considered by lettuce farmers.

- It is vital to utilize approved seeds and seedlings.

- Disease outbreaks might be avoided by using disease-resistant cultivars.
- In certain circumstances, encouraging natural insect foes (such as ladybugs) might be beneficial. Consult a licensed agronomist in your area.
- To protect lettuce plants from pests, row coverings are commonly utilized.
- Our crops may be protected from a variety of pests using nets.
- Fertilizers should not be used in excess.
- Some illnesses can be combated through weed management and crop rotation.
- Chemical control techniques are only permitted after consultation with a professional agronomic in the area.

5.7 Lettuce Harvesting

From seeding to harvesting, lettuce can take anywhere from 65 to 130 days, depending on the type. Between 30 to 70 days after transplanting, lettuce may usually be harvested. The best time to harvest our plants is determined by a variety of factors, including weather, planting distances, ideal market weight, fertilizer, and so on.

Things to remember when harvesting lettuce:

- It's best to avoid harvesting plants that are too mature. Because their leaves have a bitter flavor, it's best to pick them while they're still young, just before they reach maturity.
- The outer leaves of leaf lettuce can be removed to harvest the lettuce. As a result, the inner leaves those closest to the plant's heart can continue to grow.
- We must inspect our field on a regular basis for plants that are ready to be harvested.
- Early in the morning, before the sun rises, is the best time to gather lettuce. Some lettuce producers believe that this time of day is ideal since lettuce plants are not exposed to direct sunshine.
- Farmers keep lettuce in a cool, but not freezing, spot after harvesting.

5.8 Lettuce Yield Per Hectare

A hectare of lettuce produces 20-40 tons of lettuce on average. Remember that 1 ton equals 1000 kg = 2200 lbs., and 1 hectare equals 2,47 acres = 10.000 square meters. In regions with the right climate, experienced lettuce farmers may collect 20-40 tons per hectare over 2-4 seasons each year. Of course, experienced farmers who have practiced for several years may achieve such large yields [36].

Chapter 6

Hydroponic Lettuce Experiment

In this chapter, an experiment about hydroponic lettuce had been done by Dr. Melissa Brechner, Dr. A.J. Both, Cornell Controlled Environment Agriculture (CEA) Staff. This hydroponic greenhouse production system was created for small businesses to supply local head lettuce production as well as jobs. The team has tried a variety of hydroponic systems and discovered that the floating system is the most reliable and tolerant of them all. This system is designed to produce consistently 365 days a year. This necessitates a high level of environmental control, such as additional lighting and adjustable shade, in order to deliver a certain amount of light, which results in a predictable amount of daily development.

6.1 Nursery or Seedling Production Area

The seedling production area is where lettuce is grown for the first 11 days. Seedlings grow best in a regulated environment with continuous illumination, temperature, relative humidity, carbon dioxide, and watering. These requirements can only be reached using the following equipment in a controlled environment, [32] such as a greenhouse or a growing room:

- Ebb and Flood Benches, Tables, or Ponds
- Solution Tank and Plumbing
- Supplemental Lighting Aspirated sensor Box
- Sensors

6.1.1 Ebb and Flood Benches

Ebb and Flood benches (about 2.5 by 1.3 m or 8 by 4 foot) as shown in figure 6.1 are periodically flooded (2 to 4 times per day for around 15 minutes) to provide consistent water and nutrients to sprouting plants. These benches were created with the intention of supplying water and nutrients via sub-irrigation. The fertilizer solution is injected into the Ebb and Flood bench through a pump and pipes. After a set amount of time, the solution is automatically drained [32].

Figure 6.1: This is a photo of an empty Ebb and Flood bench while the bench is flooding for sub-irrigation.

Alternatively, the rockwool slabs in trays placed on a bench or at the edge of a pond as shown in figure 6.2 can be irrigated from above with a hose equipped with a breaker that slows the flow of high-velocity water to avoid damaging fragile seedlings [32].

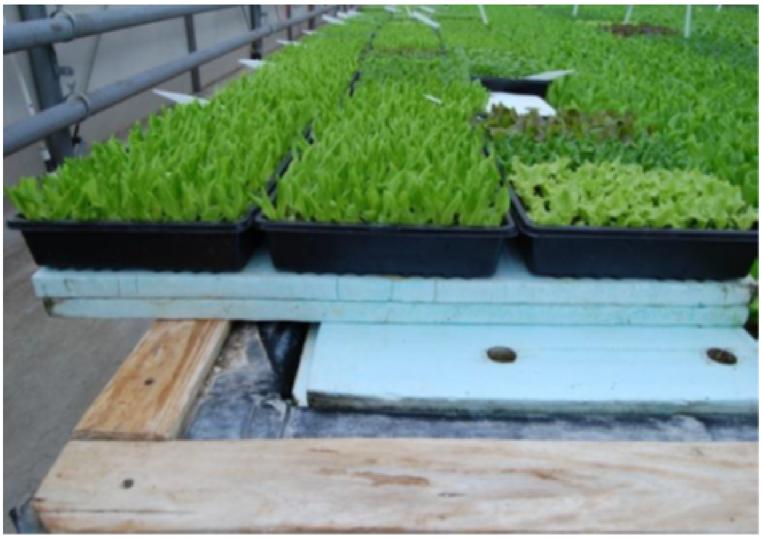


Figure 6.2: Seedling area on edge of pond in greenhouse.

Humidity coverings in the figure 6.3 are used to keep the developing seeds in a high-humidity environment. If you're using bare seed, you'll need these [32].

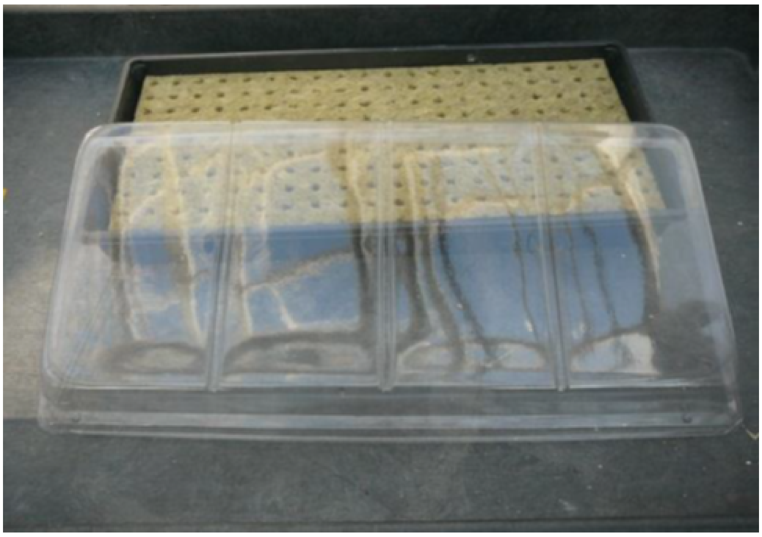


Figure 6.3: Humidity cover propped against a sheet of rockwool.

6.1.2 Solution Tank and Plumbing

The nutrient solution used for sub-irrigating the seedlings is kept in a fiberglass tank (A) see the figure 6.4. A plastic tank might be used instead of the fiberglass tank, although it might not be as sturdy. If the germination area is in a greenhouse, care must be made to find a plastic vessel that will not disintegrate fast in sunlight. Any container used should be opaque enough to avoid algae growth. To prime the system, fill the bench, and provide nutrient solution for the first 11 days of development for about 2000 seedlings, approximately 250 L (66 gallons) of nutrient solution is necessary. The solution is pumped to the bench using a tiny (1/50 h.p.) pump (B). The plumbing (C) should be adaptable to the demands of each germination region. The flow of the nutritional solution to the Ebb and Flow bench is controlled by a throttling or gate valve (D). In the shot above, the bottom of the sub-irrigation bench (E) can be seen. The pump may be set to run on a timer, allowing irrigation to take place without the need for human participation [32].

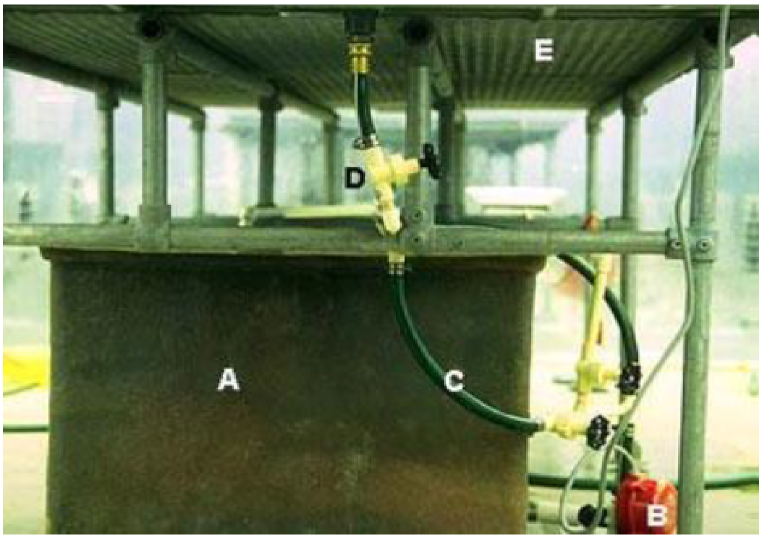


Figure 6.4: Nutrient solution reservoir fiberglass tank (A), Pump (B), Piping (C), and Valve (D). The bottom of the germination bench can be seen in (E).

6.1.3 Lighting

There is 2 parts of vertical farm to be lighting which it's germination room and green house:

Germination Room

Room for Germination In general, a separate chamber for seedling germination consumes a lot of energy. We found that the improvement in development attained by using a germination chamber was not worth the considerable quantity of energy it used, therefore we stopped using it. High-pressure sodium/metal halide (A,B, see Figure 6.6) or cool white fluorescent (CWF) lights (A, see first Figure 6.5) are suggested. To keep the temperature set points, the heat created by the lights must be dispersed from the germination region. The use of incandescent bulbs (B) is discouraged since the red light they generate encourages seedlings to 'stretch.' Fluorescent lamps emit a lot of blue light, which causes seedlings to be compact and strong [32].

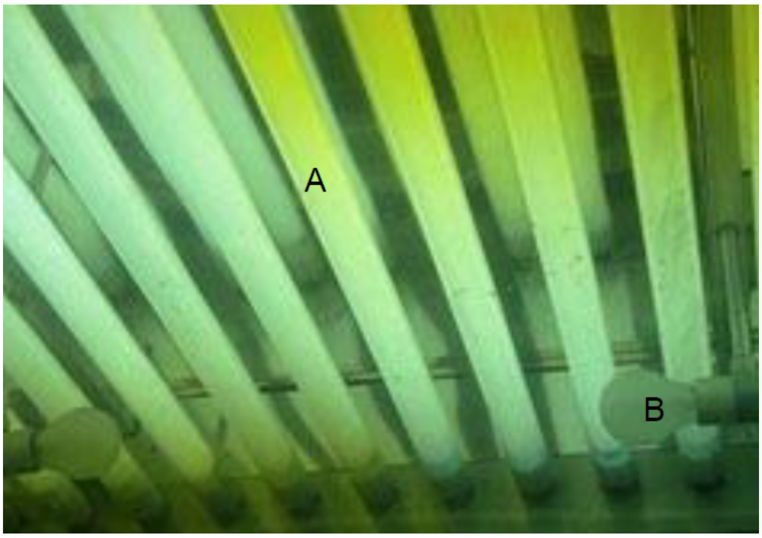


Figure 6.5: Fluorescent (A) and incandescent (B) lighting in the growth room. Fluorescent lighting is used for plant biomass production and incandescent lighting is used for photoperiod control.

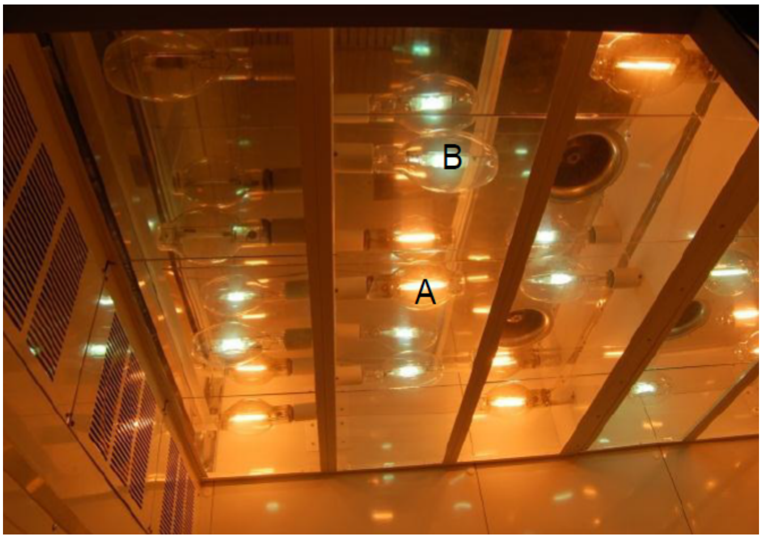


Figure 6.6: High Pressure Sodium (A) and Metal Halide (B) lamps in a growth chamber.

Green House

High-intensity discharge (HID) luminaires, such as high-pressure sodium (HPS) of metal halide (MH), are suggested for seedling germination in a greenhouse (Figure 6.7).

Figure 6.7: High Intensity Discharge (HID) luminaire in a greenhouse.

6.1.4 Pond Area

The following are the themes included in the pond area:

- Pond Size
- Construction
- Pond Design
- Lighting
- Paddle Fan
- Aspirated Box

Pond size

A 660 m2 growing space, for example, is required to produce 1245 heads every day. The lettuce plants are cultivated for 21 days in the pond area. At Day 21, the plants were re-spaced from 97 plants per m sq to 38 plants per m sq [32].

Construction

Pond construction may be divided into three categories:

- The pond might be recessed in the greenhouse floor, with the water surface barely above the bottom.
- On top of the greenhouse's floor, a containerized pond with concrete or wood walls (Figure below) can be built.
- The pond can be created on an island of fill, with the ponds built into the fill to reduce the amount of bending required when working with the crop. It is crucial to remember that a greenhouse using this technique must be tall enough so that the supplementary lighting does not shine too near to the plants.

In any case, the pond floor can be covered with sand to prevent sharp edges from puncturing the polyethylene lining. A thick plastic liner (for example, 0.5 mm poly) is subsequently fitted as the primary barrier for leak prevention. To avoid leakage, certain steps should be followed [32].

Figure 6.8: Empty pond with liner.

Design

On Day 21, the pond area is intended to allow for one plant spacing (also known as re-spacing). Multiple ponds operate in parallel to aid in the spacing procedure. Between days 11 and 21, the plants are cultivated in one of the ponds. After re-spacing (from 97 plants m-2 to 38 plants m-2) the plants are transferred to one of the remaining ponds and grown for two weeks (day 21 through day 35) [32].

Lighting

In the Pond Growing Area, uniform light dispersion is essential. A supplementary light intensity of 100-200 mol/m2/s (for a total of 17 mol/m2/d1 of combined natural and supplemental illumination) is recommended at the plant level. It should be mentioned that the light integral that worked best for the particular variety of Boston bibb lettuce that we employed was 17 mol/m2/d. For certain cultivars, the maximum quantity of light that may be utilized before the physiological condition known as tipburn occurs is 15 or mol/m2/d. High pressure sodium (HPS) lamps are a type of High Intensity Discharge (HID) lamp that is used to provide lighting. These lamps are relatively efficient, have a long life (25,000 hours, on average, these lamps lose 1% output every 1000 hours), and gradually lose output over time. A recent advancement in the production process for metal halide lamps has resulted in a lifetime comparable to that of high-pressure sodium lamps. Metal halide lamps emit a somewhat more efficient spectrum for plant development than high pressure sodium lights. A new Philips bulb has accentuated the benefits of metal halide lamps, such as moving more light production to the blue and red regions of the spectrum and lowering the luminaire's heat output. Independent lighting experts use sophisticated software to calculate the number and location of bulbs required to provide a given and consistent light intensity. The installation of the proper lighting system is critical.

Because the CEA lettuce program is so labor-intensive, it needs a lot of lights and electricity. Special tariffs and rebate schemes for new enterprises and Controlled Environment Agriculture facilities should be available from local power companies [32].

Lighting Configuration and High Intensity Discharge (HID) Lamps

A customized lighting configuration computer software was used to determine the quantity and placement of the lamps. a supplementary lighting bulb and luminaire made of high-pressure sodium (HPS). To augment natural light, these lights deliver the required Photosynthetically Active Radiation (PAR). The supplementary lighting system is adjusted (on and off) by the computer control software to reach a specified total light level each day. The recommended amount for lettuce production is 17 mol/m2/d [32].

Paddle Fan

At a rate of 140 cubic feet per minute, an overhead fan (paddle fan - Figure 6.9) blows air vertically down onto the lettuce plants. Plant transpiration is increased as a result of the increased airflow. The movement of nutrients, particularly calcium, from the roots to the young, fast-growing lettuce leaves is aided by increased transpiration. The increased rate of nutrition transport ensures that sufficient calcium reaches the leaves, preventing tipburn. Without this airflow, lettuce must be cultivated in low-light conditions, which hinders growth. Cultivar selection, spacing, and airflow all influence the daily light integral aim that may be accomplished with and without vertical airflow before tip burn occurs. The figures above are only samples of what has worked in our scenario; they are not the sole answer, and no attempt was made to determine airflow maxima and minima [32].

Figure 6.9: Paddle fan to increase vertical air movement and therefore evapotranspiration. This is important for the prevention of tipburn.

Aspirated Box

The aspirated box located in the pond area has the same function as the aspirated box in the germination area.

Figure 6.10: Aspirated box with digital output screen in greenhouse.

6.2 Computer Technology and Monitoring

In the production of hydroponic lettuce, computer technology plays a crucial role. To regulate the abiotic environment, a computer control system (such as Argus, Hortimax, or Priva) should be utilized. The characteristics of the greenhouse environment are monitored using a variety of sensors. Temperatures of greenhouse air and nutrient solution, relative humidity and carbon dioxide concentrations of greenhouse air, light intensities from sunlight and supplemental lighting, pH, Dissolved Oxygen (DO) levels, and Electrical Conductivity (EC) of the nutrient solution are some of the parameters that are measured. The ambient conditions will be sent to the control computer, which will trigger environmental control methods including heating, ventilation, and lighting [32].

6.2.1 Biological Significance of Environmental Parameters

Temperature

Plant growth is influenced by temperature. Chemical reactions tend to speed up as temperatures rise. Enzymes manage the majority of chemical reactions in plants, and they work best at specific temperatures. Enzyme activity begins to decline above and below certain temperature ranges, and chemical activities begin to stall or cease as a result. Plants get stressed at this moment, their development slows, and the plant may finally die. For a quick and successful development, the temperature of the plant's surroundings should be kept at optimal ranges. Temperatures must be monitored and managed in both the air and the water [32].

Relative Humidity

The transpiration rate of plants is influenced by the relative humidity (RH) of the greenhouse air. High greenhouse air RH causes plants to transpire less water, resulting in less transfer of nutrients from roots to leaves and less cooling of leaf surfaces. In rare circumstances, high humidity might also create sickness concerns. High relative humidity, for example, promotes the formation of botrytis and mildew [32].

Carbon Dioxide or CO2

The quantity of photosynthesis (growth) that plants do is directly influenced by the CO2 content in the greenhouse air. The average CO2 content in the air is roughly 390 parts per million (ppm). On a bright day, plants in a confined greenhouse may deplete CO2 concentrations to 100 ppm, drastically slowing photosynthesis. Increasing CO2 concentrations to 1000-1500 ppm in greenhouses accelerates growth.

Liquid CO2 is used to supply CO2 to the greenhouse. Heaters that produce carbon dioxide as a by-product are available, but we do not suggest them since they frequently produce air pollutants that stifle lettuce growth [32].

Lights

A quantum sensor is used to monitor PAR (Photosynthetically Active Radiation), which is measured in mol/m2/s. PAR is a kind of light that is beneficial to plants during the photosynthesis process. PAR measurements indicate the amount of photosynthesis and growth that the plant is capable of performing. Because they do not directly detect the light utilized for photosynthesis, foot-candle sensors and lux meters are ineffective [32].

Dissolved Oxygen

The quantity of oxygen available in the pond nutrient solution for the roots to utilize in respiration is measured as dissolved oxygen (DO). At a DO level of at least 4 ppm, lettuce will grow well. DO levels will plummet to almost 0 ppm if no oxygen is given to the pond. The lack of oxygen in the fertilizer solution will halt the plant's respiration mechanism, causing catastrophic damage and death. In the ponds, pure oxygen is introduced to the recirculation system. Typically, the level is kept between 8 and 10 ppm (no advantage to 20). It is feasible to add air to the solution using an air pump and an aquarium air stone for small systems, but the dissolved oxygen level reached will not be as high as with pure oxygen [32].

pH

The concentration of hydrogen ions in a solution is measured by its pH. A solution's pH can vary between 0 and 14. The pH of a neutral solution is 7. That is, the number of hydrogen ions (H+) and hydroxide ions is equal (OH-). Acidic solutions contain a higher concentration of H+ and have a pH range of 0-6.9. Basic or alkaline solutions with a pH of 7.1-14 have a higher concentration of OH-. The availability of fertilizer salts in a solution is controlled by the pH of the solution. For the given lettuce growth method, a pH of 5.8 is ideal, but a pH range of 5.6-6.0 is acceptable. Nutrient deficits can arise at levels that are either too high or too low [32].

Electrical Conductivity

The dissolved salts in a solution are measured by electrical conductivity (EC). Because there are less salts in the solution when nutrients are taken up by a plant, the EC level drops. Alternatively, as water is withdrawn from the solution by evaporation and transpiration, the EC of the solution rises. If the EC of the solution rises, clean water (e.g., reverse osmosis water) can be added to decrease it. If the EC drops, a tiny amount of concentrated nutrient stock solution can be added to raise it. Make careful to remove the base EC of your source water from the amount reported by your sensor when monitoring the EC concentration [32].

Here are the parameters to be set up for hydroponic lettuce plantation [32]:

- Air Temperature: 24 C Day/19 C Night (75 F/65 F)
- Water Temperature: No higher than 25C, cool at 26C, heat at 24C
- Relative Humidity: minimum 50 and no higher than 70%
- Carbon Dioxide: 1500 ppm if light is available, ambient (390 ppm) if not
- Light: 17 mol m-2 d-1 combination of solar and supplemental light
- Dissolved oxygen: 7 mg/L or ppm, crop failure if less than 3 ppm
- PH: 5.6-6
- Electric Conductivity: 1150-1250 micro S/cm above the source water

6.3 Lettuce Production

Day 0 - Planting

Making the germination medium is the first step in the process. The media is enough to fill seven 200-plug trays (1 rockwool cubes with 10 × 20 cells per sheet). Each plug contains one lettuce seed. An automated seeding machine, such as a drum seeder or a vacuum seeder, can be used to do this. To eliminate pockets of high pH pollutants, rockwool should be wet with a nutrient solution with a low pH, such as 4.5.

The trays are put in a germination area, which might be an Ebb and Flood bench, a table, or a pond float. Every 12 hours, the trays on an Ebb and Flood bench are sub-irrigated with RO water for 1/4 hour. If a germination room is employed, illumination is kept at 50 mol/m2/s for the first 24 hours with a photoperiod (day duration) of 24 hours to guarantee optimal germination. In the germination room, the temperature is adjusted at 20°C (68°F). Plastic humidity covers can be placed over the seed trays to maintain a high relative humidity and avoid desiccation.

24 hours after planting, a fertilizer solution is given to the top or sub-irrigation water. The water's EC is kept at 1200 S/cm1 above the EC of the source water. When the pH of the solution is too high, it is corrected to 5.8 by the addition of a basic, potassium hydroxide (KOH), and nitric acid. The temperature is increased to 25 degrees Celsius, and the light intensity is increased to 250 mol/m2/s. For the balance of the crops' stay in the germination area, these environmental parameters are maintained. Until Day 6, sub-irrigation is continued for 1/4 hour every 12 hours. The photoperiod has remained unchanged at 24 hours. If hand-watering is utilized, the same watering frequency is not required, but care must be taken to avoid drying out the medium [32].

Figure 6.11: hydroponic lettuce day 1.

On Day 2, the humidity covers that were in place on Days 0 and 1 are removed. As can be seen in the accompanying shot, the seed has germinated and the radicle has begun to penetrate into the earth. The seed must not desiccate during the first two days of germination because of the high humidity. Low light levels over the first 24 hours work in tandem with high humidity to keep seeds from drying out too quickly [32].

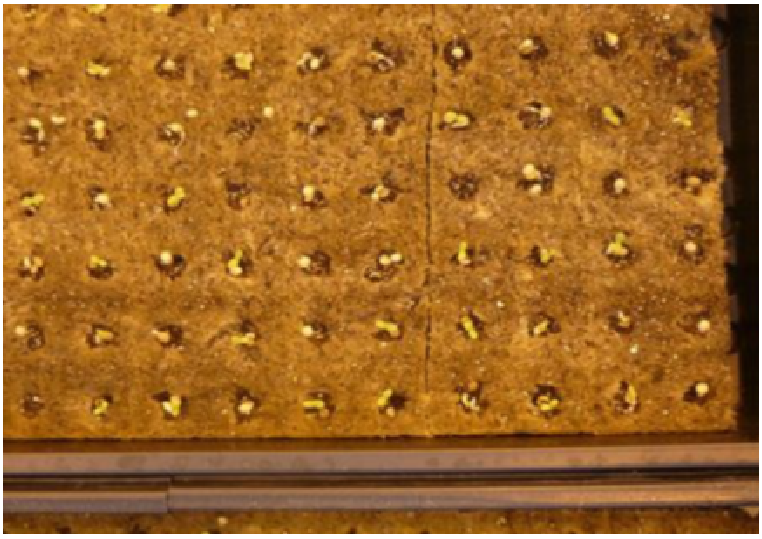


Figure 6.12: Decreasing humidity in day 2.

To produce a consistent yield, any duplicate seedlings should be removed from the plugs on Days 3 or 4. Any seedlings that are unusually big should be removed so that the growth of nearby plants is not hampered. At this point, the germination percentage can also be assessed in order to check seed quality and adequate growth circumstances. Having stable climatic conditions and plant development is crucial during this period [32].

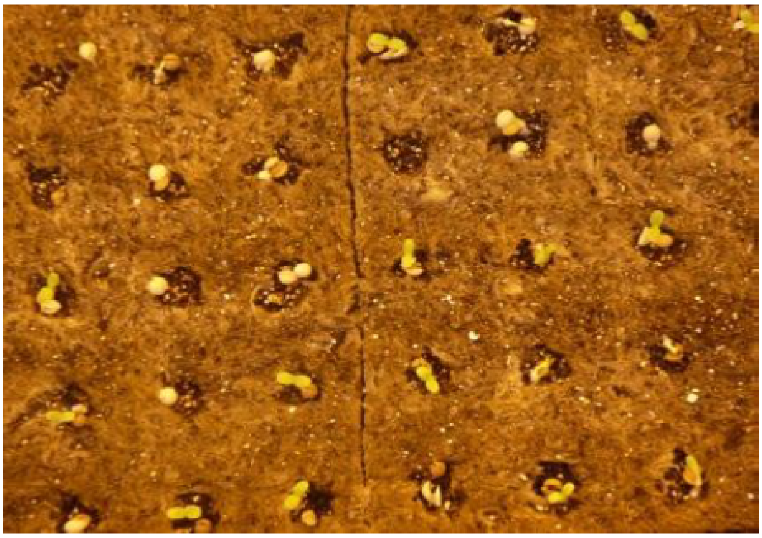


Figure 6.13: day 3 Removing double seedling.

The lettuce seedlings have matured to the point where they now require more frequent watering. If employing an ebb and flood table, the sub-irrigation system is set to flood four times each day, or every six hours, lasting 1/4 hour each time (15 min). Once a day top watering with a breaker should enough [32].

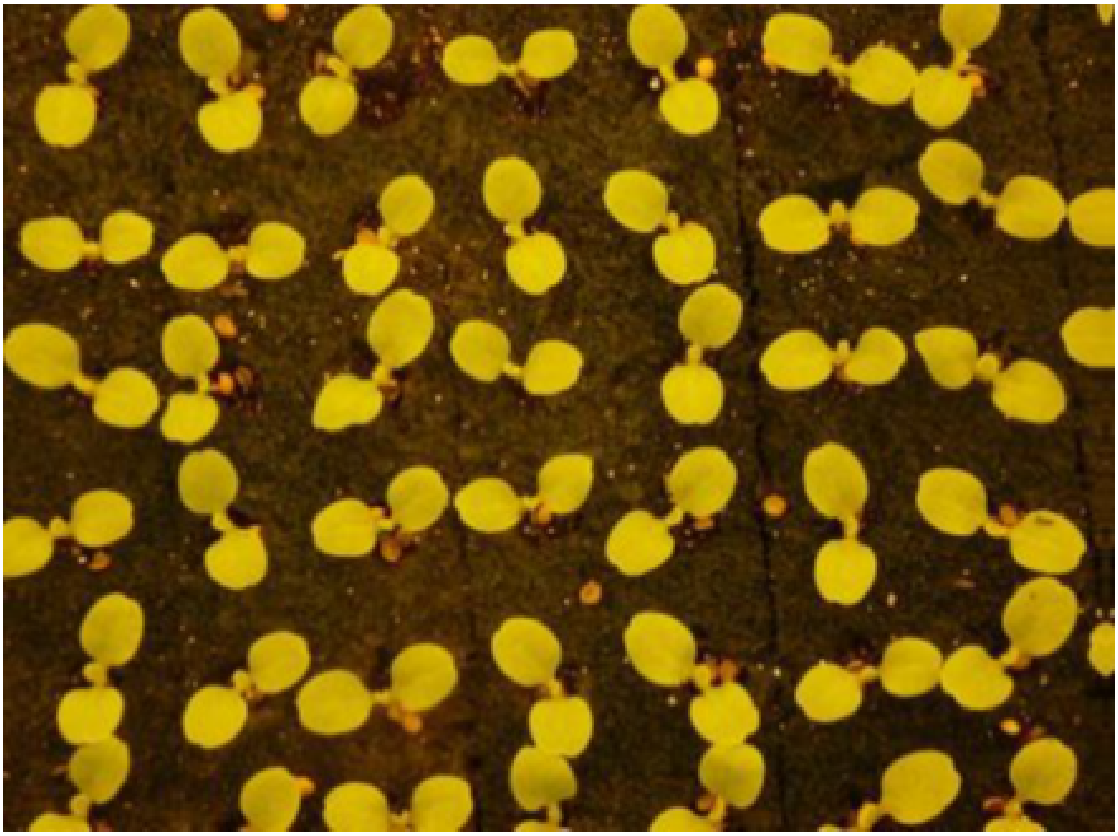


Figure 6.14: day 6 increasing watering frequency.

The leaves are starting to overlap on day 11. The seedlings' roots had grown through the plug tray's bottom. Avoid harming the exposed roots when carrying the plugs to the pond area [32].

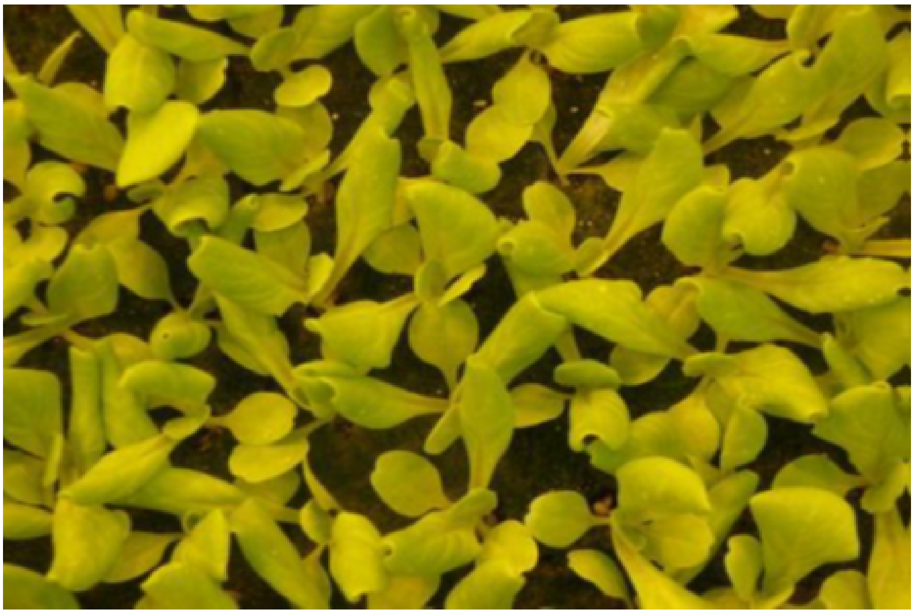


Figure 6.15: Day 11 leaves are beginning to overlap.

The lettuce in the figure 6.16 is shown after being transplanted into the floats.

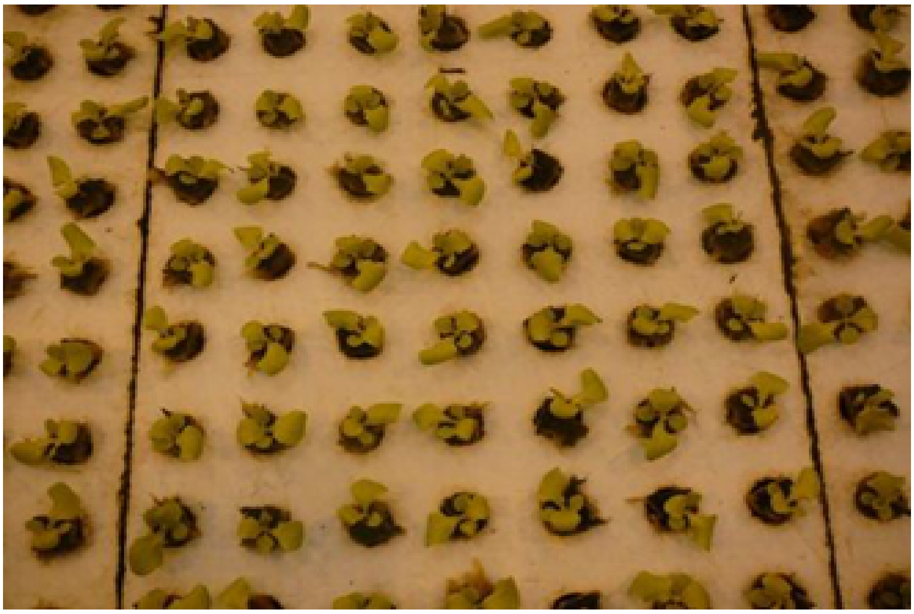


Figure 6.16: Lettuce being transplanted into the floats.

6.4 Transplanting

The seedlings are moved to the greenhouse and placed into the pond on Day 11. The seedlings are properly sub-irrigated prior to transplantation. Transplanting can be timed to coincide with typical sub-irrigation intervals to avoid desiccation during the transfer.

In Styrofoam floats, the seedling plugs float in the pond. Each float is made from 1 insulation and is hand-drilled. Drilling is sped up by placing a wooden template over the Styrofoam board to be drilled. If the board shape allows, a drill press can be employed. If a creative drill press equipment is developed, many holes can be drilled at the same time [32].

Figure 6.17: Styrofoam Floats

Figure 6.18: day 21 Transplant.

After transplanting lettuce, it is collected every 30-35 days. Seedlings are propagated 14 days previous to harvest and replanted immediately after harvest to provide a constant supply [32].

Figure 6.19: Day 35 harvest

6.5 Packaging and Post-Harvest Storage

Between each growth cycle, Styrofoam floats are cleaned with a mild bleach 2% solution.

Depending on the materials that clients want, packaging might be a substantial expense. Frequently, both a product package and a box to transport the goods must be acquired. Options:

- With or without roots in clamshell
- Clamshell or bag – lettuce bouquet with or without roots
- The lettuce should be kept at 40 degrees Fahrenheit once it has been wrapped.

The crop is sold at the current market price. The average weight is calculated by dividing the total weight of leaves by the total number of plants, and it was used to calculate income and perform economic analysis [32].

6.6 Crop Health

Infection

It's critical to keep your crop healthy. Powdery mildew can be a concern when growing lettuce in the winter. Before the crop is planted, a strategy for mildew treatment should be in place, as well as adequate chemical controls.

The following are guidelines for keeping a healthy greenhouse environment:

- Keep the crop fast growing by supplying appropriate light, nutrients, and other environmental conditions at all times.
- If root disease is discovered, the ponds and solution tanks should be drained, and the crop should be sacrificed. A 2 percent bleach solution should be used to clean the ponds and tanks. Other sanitation solutions, such as Greenshield, are readily accessible. It's possible that the disease started in the Germination Area, so that area should be cleaned as well, including the benches and solution tanks.
- Using a 2% bleach solution, clean the Styrofoam floats, trays, and other equipment. To avoid the transmission of disease, the equipment should be cleansed after each usage.

- No other plant material or soil should be brought inside the greenhouse. This item might include pests and diseases that could harm your crop. Reduce the number of visitors to the greenhouse or enable them to only see the producing area from the outside.

- Ensure that the solution tanks are tinted in some way. Algae thrive in moist, well-lit environments, and the solution tank is great for this. Algal development is inhibited by shading the tanks, input and output pipes, and other "wet" equipment. The algae will not hurt the crop directly, but they may make it more susceptible to disease [32].

Pests

Pests can be a concern in hydroponic lettuce cultivation, although they are rarely a big issue. Shore flies, fungus gnats, thrips, and aphids are examples of insect pests that can be encountered in conjunction with hydroponic lettuce cultivation. Plants that develop quickly have a hard time establishing a pest population.

Pest populations may be able to establish themselves if agricultural output is maintained. Pests can be kept out of a facility by taking precautions including inspecting possible access points (ventilation inlets). Keeping grass and weeds cut outside the greenhouse or completely eradicating all vegetation can help to lessen insect pressure inside.

There aren't many insecticides approved for use on greenhouse veggies. Biological pest management is an effective yet underutilized option. Nicotine was attempted as an aphid deterrent, but it not only failed to suppress insects, but it also left a flavor on the lettuce [32].

6.7 Vertical Farming Model System Analysis

6.7.1 IDEF0 Functional Specification

IDEF-0 is a structural diagram that provides an operational representation of functions, processes, and activities in the system. This model is hierarchical, and an activity can be represented generally or as a set of more detailed activities. It is useful since it is a clear and intuitive way of representing processes.

The general level is A0, the more detailed levels of A0 will be A1, A2, A3... the detailed levels of A1 will be A11, A12, A13... and so on. Those levels are called child diagrams. The IDEF0 is composed of a series of diagrams, identified by data and objects interconnected by directional arrows, and developed on several levels.

There are inputs (items that start the activity), outputs (are the results that come from performing the activity), resources (can be systems, people, equipment which are used to perform the activity) and controls (their role is guidance or regulation of the activity) and the activity are represented by a box.

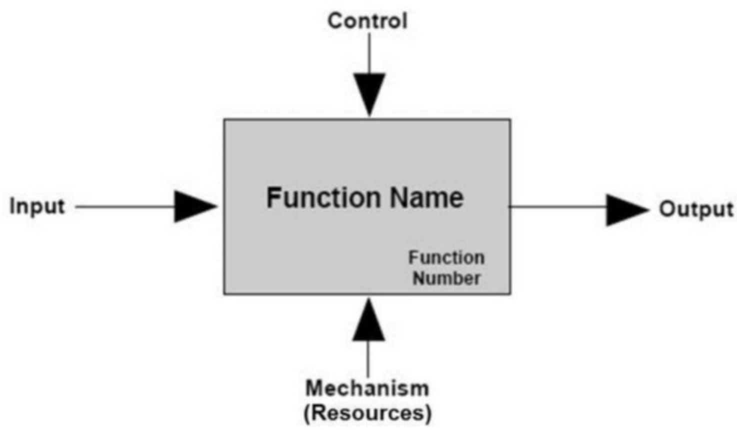


Figure 6.20: IDEF specification

6.7.2 IDEF-0 AS-IS

IDEF-0 AS-IS shows the current situation for the crop plantation before any new change. Since I'd collect data and information about the sustainable vertical farms. So here we can find the process from seeding to harvesting regarding this plantation. The process is very simple, no need for more layers.

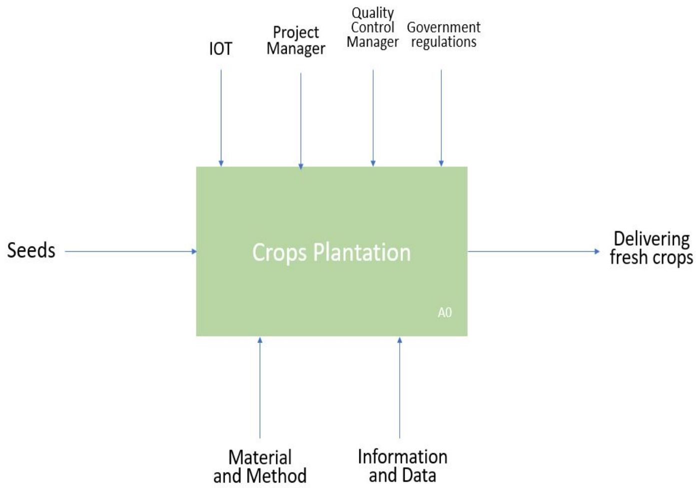


Figure 6.21: A0 General level

Input

Seeds: here we must choose what kind of crops we have to planted, could be green leaves such as lettuce, ice cabbage... etc.

Controls

When a new plantation is proposed, it will be controlled by IOT System, Project Manager, Quality Control Manager and regulated by Government Laws. Each project will be coordinated according to several requirements such as specific data, skills (hard and soft), number of employees, material, and time frame for the process.

Output

Delivering fresh crops: after the selection process, we can get a fresh product to be used in the market.

Mechanism

Information and Data: the set of components for collecting, storing, and processing data and for providing information about the crops.

Material and Methods: the list of component elements that we must use during the process and the parameter that we should set it up.

6.7.3 A0 Detailed level

In this section, the 3 detailed level of A0 from germination to harvesting phase.

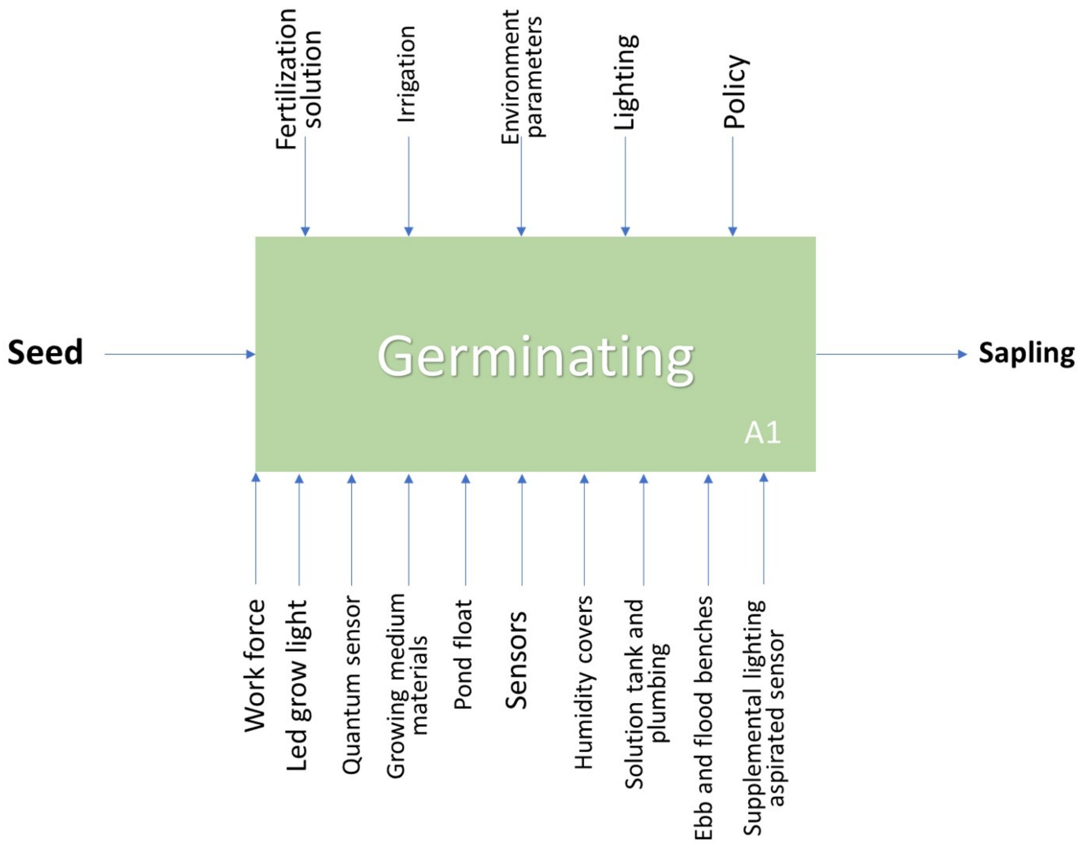


Figure 6.22: A0 detailed diagram for lettuce germination.

Germination

Germination is the first phase of the crop's plantation, starts with seeding and end with sapling. Whereas we start with using growing media trays such as rockwool, expanded clay aggregate (hydroton), coconut fibers (coco coir) ...etc. In the lettuce experiment they used rockwool (1 rockwool cubes with 10x20 cells per sheet) equal to 200 lettuce seed. To eliminate pockets of high pH pollutants, rockwool should be wet with a nutrient solution with a low pH, such as 4.5. These trays might be in the EBB and Flood bench, this trays on an EBB and flood bench are sub-irrigated with Ro water for 15 minutes in the 12 hours. If a germination room is employed, quantum sensor should be used to measure light available for photosynthesis, to keep illumination at 50 mol/m2/s for the first 24 hours with a photoperiod of 24 hours to guarantee optimal germination and the temperature is adjusted at 20°C (68°F) by using the aspirated box. Plastic humidity covers can be placed over the seed trays to maintain a high relative humidity and avoid desiccation.

24 hours after planting, a fertilizer solution is given to the top or sub-irrigation water. The water's EC is kept at 1200 S/cm1 above the EC of the source water. When the pH of the solution is too high, it is corrected to 5.8 by the addition of a basic, potassium hydroxide (KOH), and nitric acid. The temperature is increased to 25 degrees Celsius, and the light intensity is increased to 250 mol/m2/s. For the balance of the crops' stay in the germination area, these environmental parameters are maintained. Until Day 6, sub-irrigation is continued for 1/4 hour every 12 hours.

Transplanting

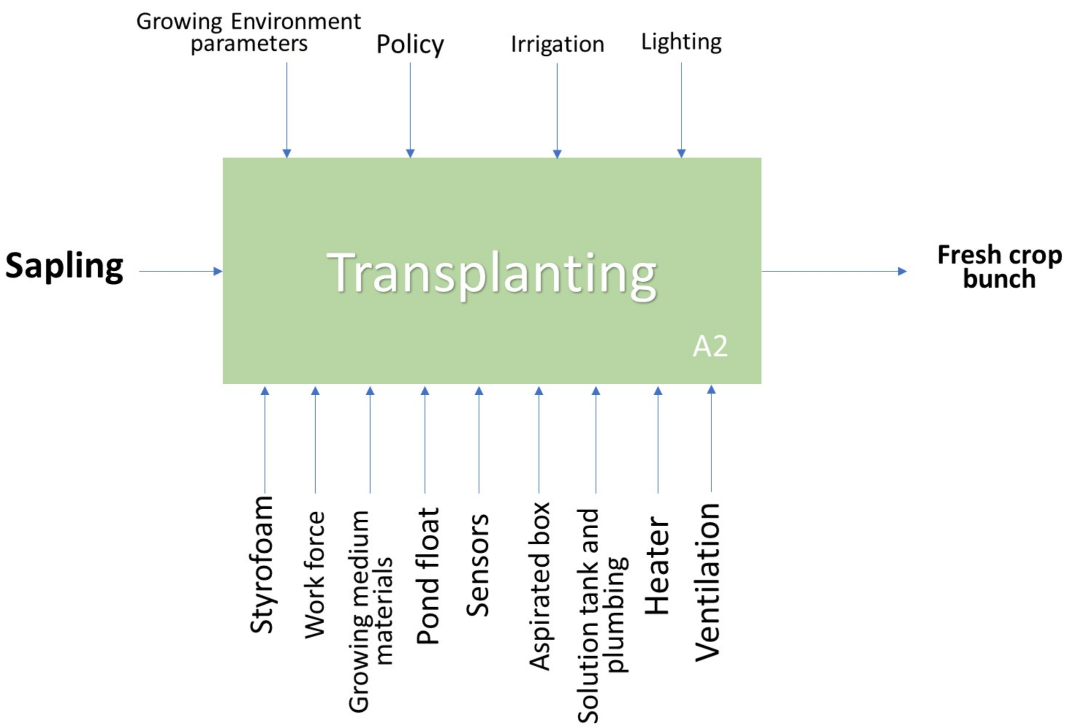


Figure 6.23: A0 detailed diagram for lettuce transplanting.

Transplanting comes after finishing from germination. Where seedlings are transported to the green house and transplanted into the pond. Transplanting can be scheduled to follow normal sub-irrigation periods in order to prevent desiccation during transfer. The seedling plugs float in the pond (660 m2 for 1245 head of lettuce) in Styrofoam floats. Paddle fan to increase vertical air movement and therefore evapotranspiration, this is important for the prevention of tipburn. Most of the mechanisms is same as the previous phase such as aspirated box to measure the relative humidity and temperature, pond float, and sensors, but parameters differ in this phase as it written below.

- Air Temperature 24 C Day/19 C Night (75 F/65 F)
- Water Temperature No higher than 25C, cool at 26C, heat at 24C
- Relative Humidity minimum 50 and no higher than70
- Carbon Dioxide 1500 ppm if light is available, ambient (390 ppm) if not
- Light 17 mol m-2 d-1 combination of solar and supplemental light
- Dissolved oxygen 7 mg/L or ppm, crop failure if less than 3 ppm
- pH 5.6-6
- EC 1150-1250 micro S/cm above the source water

Harvesting

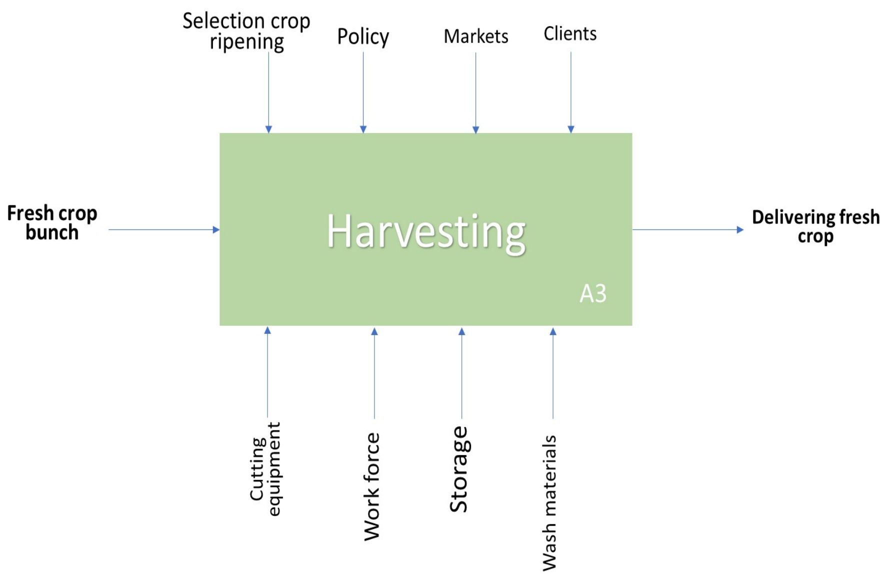


Figure 6.24: A0 detailed diagram for lettuce harvesting.

The last phase harvesting, where they should collect their crops using cutting equipment, it could be a machine or workforce. This phase could be controlled by the inventories such as markets and clients, also most of the time ripening could be controller where they should pick the ripened crops that have all specification. During this phase when they finish from collecting the crops they should wash the material for example; Styrofoam floats should be cleaned between each growing cycle with a weak bleach (2%) solution.

6.7.4 Result and Discussion

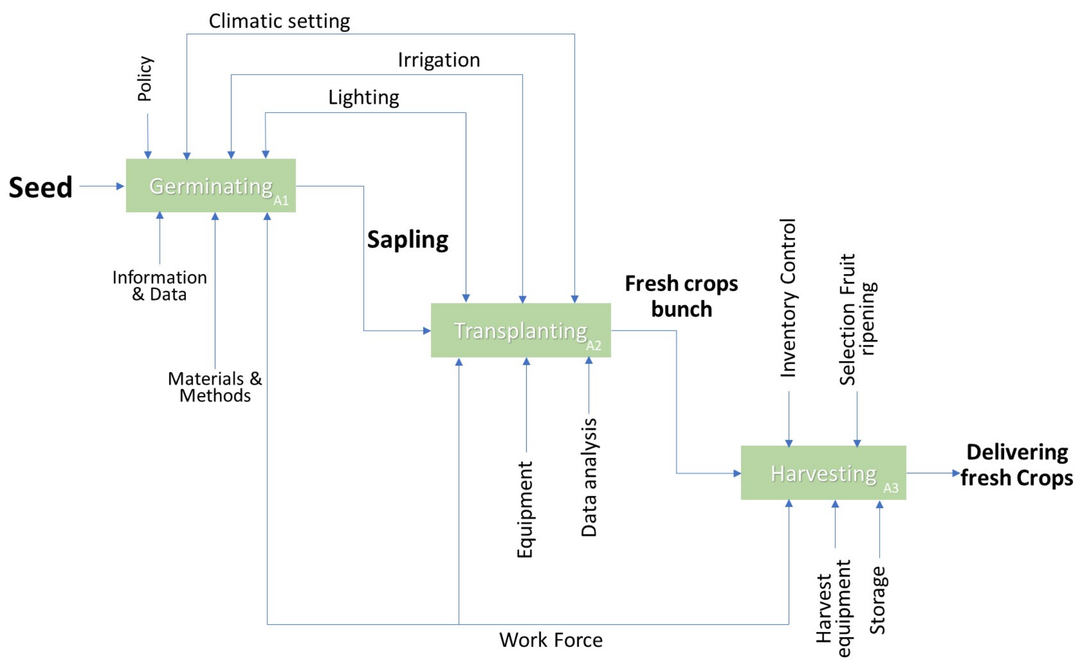


Figure 6.25: A0 General level for vertical farm

Activities

At the first phase Seedling (A1), the seed is the input for the beginning of the entire process chain. Sapling is the output for (A1) and an input for (A2). Controls in this stage are policy, light system, climatic settings, and irrigation system. Policy authorizes the standards and actions taken during this process which in other hand are also controlled by the supervisor and project management. Mechanisms in this stage are workforce, materials, and methods, also information and data. Workforce are represented by the labors in this production. Materials and methods are used related to the control system applied (watering, light, environment climate).

Information and data are gathered and measured after each step-in order to be compared with the required ones.

In transplanting (A2), the sapling to be input and the output has recognized as Fresh Crops Bunch. Controls in this stage are same as (A1) light system, climatic settings, and irrigation system. Even though the control system is similar in both phases, the standards and mechanisms are different. Material and equipment used are HID light, paddle fan, aspirated box and smart sensors. Information and data in this phase are gathered and analyzed in order to meet the standards and achieve the expected outcomes.

In the last phase Harvesting (A3), the Fresh Crops Bunch are the input which will output in delivering them. Controls in this stage are inventory control and selecting crops ripening. Inventory control is important to ensure that the company's operations function properly and that there is no stock surplus after selecting the mature crops. Mechanisms in this stage are workforce, storage and harvest equipment.

Chapter 7

Key Differences Analysis

When it comes to sustainability, farming is a critical concern. As the world's population grows and cities develop, we must consider how much land is used for food production and other crop growth. In addition to traditional farming, novel urban adaptations such as vertical farming are gaining traction. As a result, we had to inquire: What is the difference between traditional and vertical farming?

7.1 Key differences between Vertical Farming and Traditional Farming

By analyzing the essential qualities of vertical farming with regenerative conventional farming, we may gain a better understanding of the best solutions for a fairer, cleaner, and greener food future.

Vertical and conventional farming differ in some categories, whereas each one have it's strengths and weaknesses. Here is the main 3 differences:

Land Use

Plants cultivated in hydroponic systems grow quicker than those grown in soil in an average of 30 days for lettuce, allowing for more crops per year since it could be harvest 12 times and a higher profit margin.

Traditional farming is restricted to growth seasons since it have only 2 seasons for lettuce per year and each one takes 90 days to harvest so it will not give same crops as in vertical farming, but hydroponic farming may be carried out year-round, independent of outside temperatures.

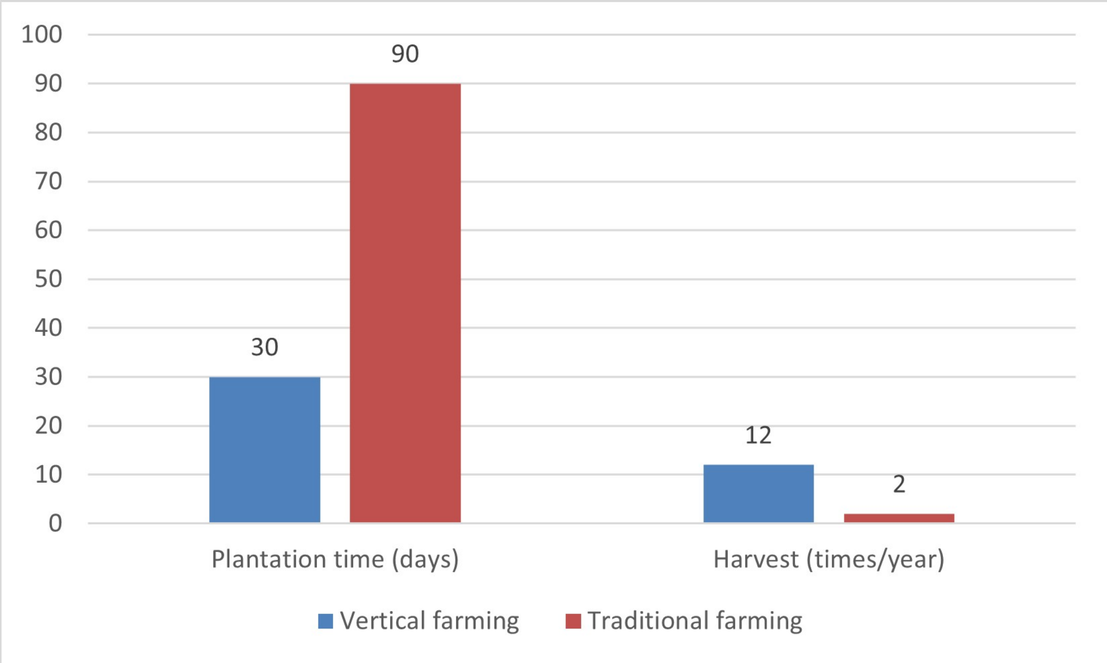


Figure 7.1: Harvest and plantation period for lettuce between vertical and traditional farming.

Regarding the lettuce production in traditional way, let's make a calculation for how many lettuce head in square meter, according to the distance between rows which should be 40 to 60 cm, while the distance between plants should be between 25 to 35 cm. So that in each one square meter we have around 6 heads. If we multiply the number of head by 2 (number of season per year) we will get 12 heads of lettuce per year per square meter. whereas the average weight for this lettuce is about 350 ± 100 grams, so in total there are 4 ± 0.2 kg/m2/year.

On the other hand, three experiments' configurations were averaged to produce a plant density of 24 plants per square meter of vertical farming and 120 plants assuming that there are 5 floors. With the use of artificial lighting and temperature controls, lettuce production may be sustained all year, with a full harvest cycle every 30 days for a total of 12 harvests each year. The average amount of edible lettuce per plant, resulting in a total mass of 144.6 grams per plant. The average production of hydroponic lettuce per year was computed in terms of kg/m2/y using estimations for plant density, number of harvests, and plant weight. So in total we will have 288 heads of lettuce per year which it's equivalent to 41.7 kg/m2/year [37].

The figure 7.2 show the results based on this analysis.

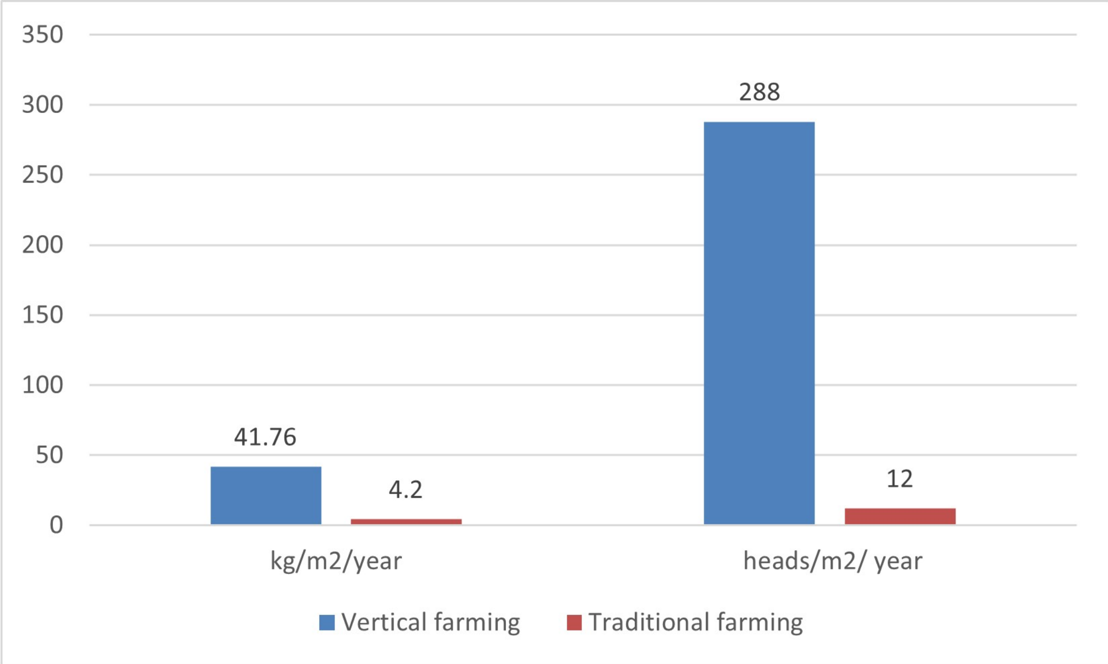


Figure 7.2: Lettuce production in vertical and traditional farming. NOTE: production in one floor for vertical farm

Water Use

In today's food systems, freshwater overuse and abuse is a serious issue. Agriculture is responsible for 70% of global water withdrawals and pollutes valuable freshwater supplies. Vertical farming conserves water and prevents pollution. Organic agricultural approaches and sophisticated water management strategies can also greatly reduce traditional farming's excessive water demand. Traditional farming may even recharge aquifers and increase rainfall by planting trees.

It has been calculated how much water is used in traditional head lettuce farming. A mean irrigation consumption estimate of 965 L/m2 for each crop was calculated using head lettuce crop budgets, and since in traditional farm there are 2 crops per year so estimated water usage is 1930 L/m2 in 2 harvests. The average value was then converted to liters per kilogram per year (L/kg/year) using the anticipated average yield value of traditional lettuce and one lettuce crop per year. Since in square meter there is 4 kg/year, so if we divide 1930 L/m2 by 4.2 kg/year we got 459.5 L/m2/year [37].

The water use for hydroponic head lettuce production was calculated for a cultivation area of 1000 m2. Every month, it harvests 3.5 tons of fresh lettuce. A daily production of this size requires 2020 liters of water, the majority of which is needed for plant nourishment (1400 liters). Daily water usage, on the other hand, is nearly three times lower. Once in the system, 2020 liters are poured. Plant roots are saturated in nutrient solution all of the time and absorb it as needed, ensuring that all macro- and microelements are present in the proper ratios and concentrations.

Plants utilize just 80 liters of water from a total of 1400 liters for weight increase. The remaining 1320 liters are simply evaporated by the plants. A lettuce leaf may evaporate a quantity of water that is several times its own weight through the process of transpiration. This water will be collected using air conditioners and dehumidifiers, purified, and reused in manufacturing while maintaining a 70 percent humidity level inside.

The farm's second source of water is the water supply system, which collects additional 700 liters before passing it through an unique filtering machine, yielding 560 liters of filtered water and 140 liters of untreated water. The latter is collected in a dedicated tank for technical purposes such as hand washing, pallet washing, floor cleaning, and so on. Also there is 120 L/day remaining in the pot as a wetting peat, and 360 L/day goes as a drainage.

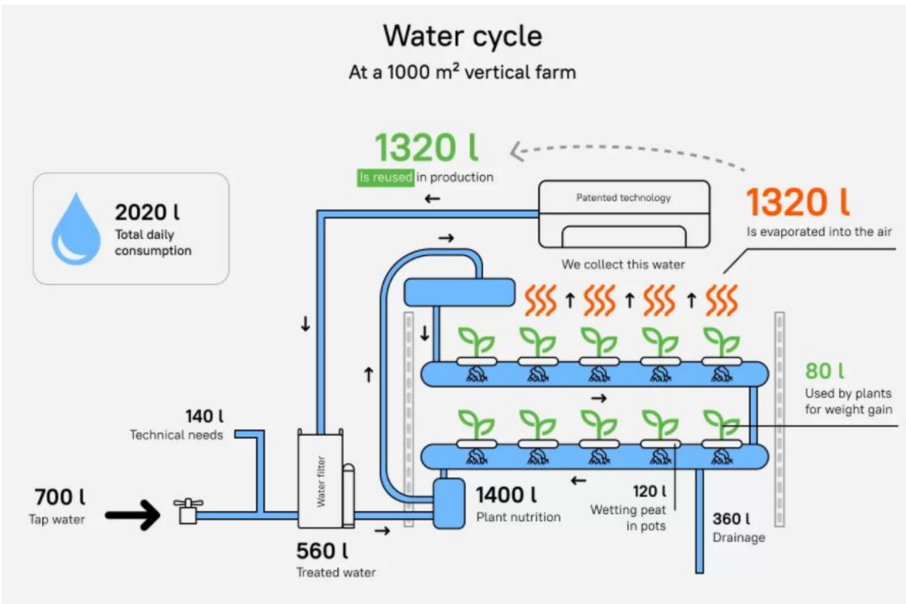


Figure 7.3: Detailed diagram about the water usage [38].

As a result, in order to maintain water, they began collecting it from air conditioners and dehumidifiers that were initially meant to keep the farm's moisture levels at an appropriate level. This method requires just 2020L at the first day then 700 liters of tap water every day until the end of harvest. So in total, vertical farm required 22.32 L/m2 per one harvest (30 days).

The difference in water usage between hydroponic and traditional lettuce cultivation is huge. The estimated water consumption for hydroponic lettuce production was 22.32 L/m2, while the anticipated water demand for traditional lettuce production was 459.5 L/m2 for each single crop.

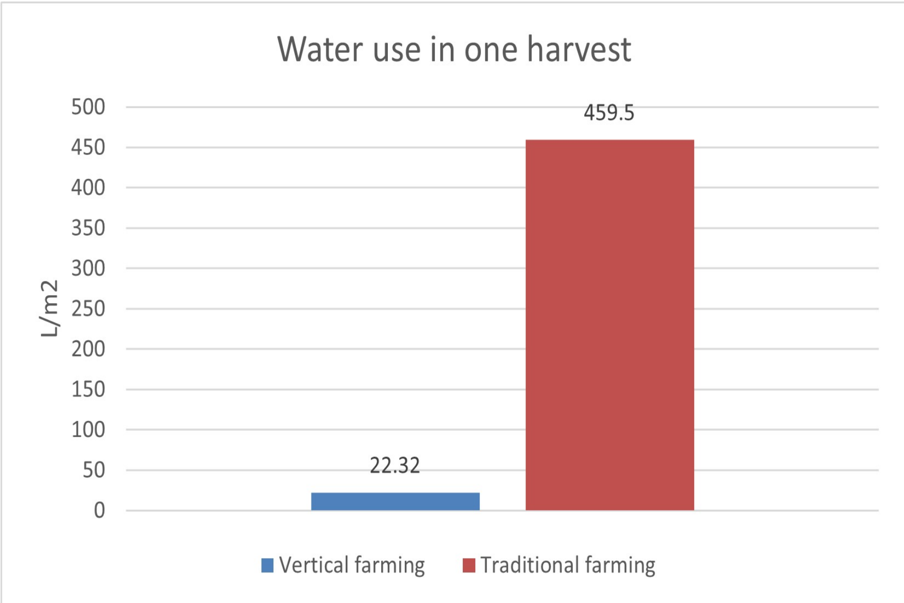


Figure 7.4: Difference in lettuce water use between vertical and traditional farming in one single harvest.

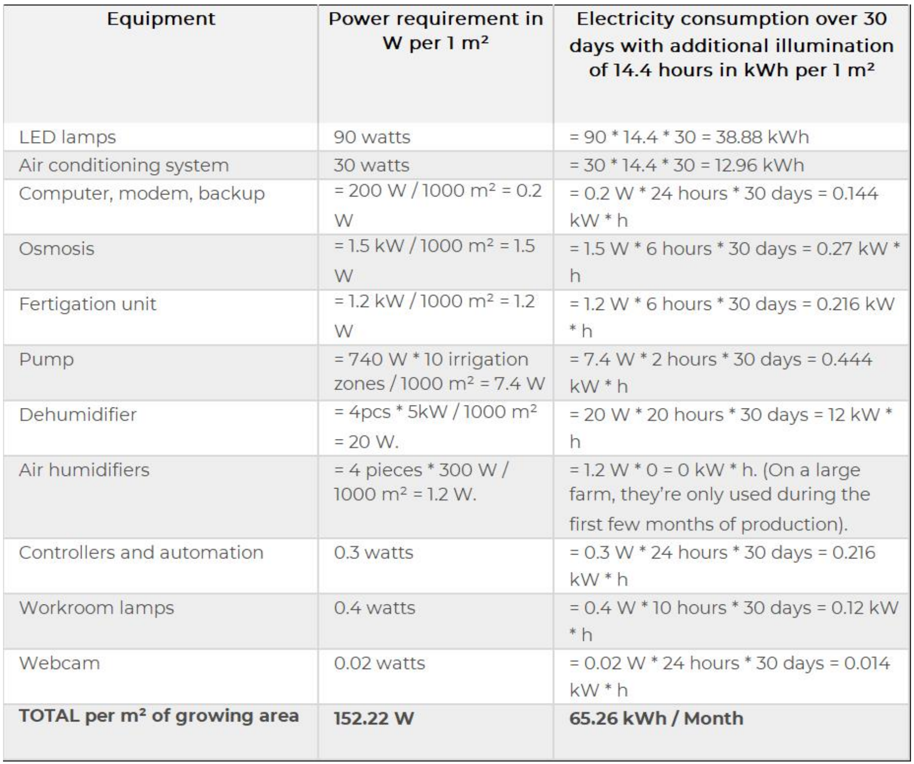
Energy Use

The use of energy in traditional head lettuce production was confined to direct use of fossil fuels by farms during operations and the use of electricity in irrigation water pumps. Budgets for head lettuce production were based on an average estimate of fuel usage. Using the projected average yield value for traditional lettuce and assuming one crop of lettuce per year, the average value was transferred to kilojoules per kilogram per year (kJ/kg/y). All farms require energy to pump irrigation water, and all pumps utilize power, it was supposed.

An average estimate of energy use for the pumping of irrigation water in units of kJ/kg was 922 for each square meter in single harvest, calculated using an estimate of 1037 kilowatt-hours (kWh) per acre foot pumped, a conversion factor of 3600 kilojoules per kWh, the previous average estimate of water use, and the estimated average yield value for conventional lettuce. [37].

The total energy used in standard lettuce production was estimated to be 1252 kJ/kg. This amount was divided between energy use for fuel use which is around 330 kJ/kg depend on the usage and groundwater pumping 922 kJ/kg. The average estimates of energy consumption for fossil fuels and irrigation water pumping were combined to create an overall average estimate of energy use in units of kJ/kg in square meter for single harvest for standard lettuce production. Since in traditional farming there is 6 Head/m2 according to previous calculation (2KG/m2 in single harvest). So that, for each head of lettuce it require 208 Kj.

The quantity of power required for the vertical farm will be determined by the crops you select. The table below illustrates how much power a 1000 m2 lettuce planting area will consume. We've calculated that one m2 adds 14.4 hours of extra illumination on average, therefore we've taken that into account:



Equipment	Power requirement in W per 1 m²	Electricity consumption over 30 days with additional illumination of 14.4 hours in kWh per 1 m²
LED lamps	90 watts	= 90 * 14.4 * 30 = 38.88 kWh
Air conditioning system	30 watts	= 30 * 14.4 * 30 = 12.96 kWh
Computer, modem, backup	= 200 W / 1000 m² = 0.2 W	= 0.2 W * 24 hours * 30 days = 0.144 kW * h
Osmosis	= 1.5 kW / 1000 m² = 1.5 W	= 1.5 W * 6 hours * 30 days = 0.27 kW * h
Fertigation unit	= 1.2 kW / 1000 m² = 1.2 W	= 1.2 W * 6 hours * 30 days = 0.216 kW * h
Pump	= 740 W * 10 irrigation zones / 1000 m² = 7.4 W	= 7.4 W * 2 hours * 30 days = 0.444 kW * h
Dehumidifier	= 4pcs * 5kW / 1000 m² = 20 W.	= 20 W * 20 hours * 30 days = 12 kW * h
Air humidifiers	= 4 pieces * 300 W / 1000 m² = 1.2 W.	= 1.2 W * 0 = 0 kW * h. (On a large farm, they're only used during the first few months of production).
Controllers and automation	0.3 watts	= 0.3 W * 24 hours * 30 days = 0.216 kW * h
Workroom lamps	0.4 watts	= 0.4 W * 10 hours * 30 days = 0.12 kW * h
Webcam	0.02 watts	= 0.02 W * 24 hours * 30 days = 0.014 kW * h
TOTAL per m² of growing area	**152.22 W**	**65.26 kWh / Month**

Figure 7.5: Detailed energy used [39].

So, vertical farm consume 65.26Kwh/month in one m2. According to calculation before, the total production of lettuce is 41.7 per year if we divide it by 12 month we will get 3.48 kg per month which it's one harvest. After that, we have to divide 65.26 Kwh/month by 3.48/month so we will get 18.75 Kwh/kg. In one kg of vertical lettuce we have 6.89 head knowing that the weight for each head is 144.6 grams. So in order to get the energy needed per each head, we have to divide 18.75 by 6.89 so we will get 2.7 Kwh/head which it's equivalent to 9789 Kj/head.

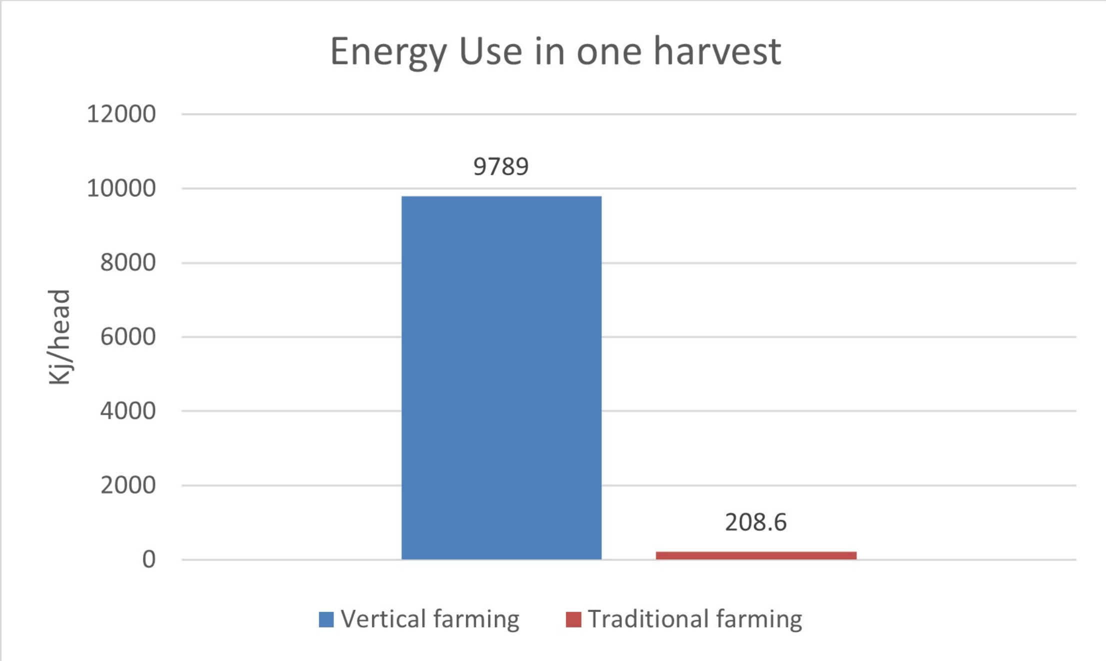


Figure 7.6: Difference in lettuce energy use between vertical and traditional farming in one single harvest.

In the table 7.1 there are the summary of lettuce plantations key differences between vertical farming and traditional one.

	Vertical Farming	**Traditional Farming**
Harvest Season (times /year)	12	2
Plantation period (days)	30	90
Lettuce production (kg/m2/year)	41.7 (only 1 floor)	4
Lettuce production (heads/m2/year)	288 (only in 1 floor)	12
Water Use (L/m2)	22.32	459.5
Energy Use (KJ/head)	9789	208.6

Table 7.1: Lettuce plantation main key differences Between Vertical Farming and Traditional Farming

Hydroponics is a promising technique in terms of land, and water use whereas it produce 41.7 kg per square meter which it's much greater than that in traditional 4.2 Kg per square meter per year, while vertical farm consume around 22.32 L/m2 which it's much better than that in traditional one which consume 459.5 L/m2 in single season. Despite its high energy requirement which it's 9789 KJ/head in one season which it's high comparing to that one in traditional farming 208.6 KJ/head in single season. A number of issues might have an impact on the future viability of hydroponic crop production, particularly lettuce. The cost of maintaining a hydroponic greenhouse's controlled atmosphere may reduce as more advanced control systems become available. Increased demand will also effect feasibility due to future supply of water, land, and food. As land and water become increasingly scarce, city planners will be more interested in hydroponic systems that are more efficient with both. Government and grass-roots support may also have an impact on the future of hydroponic farming, as subsidies may be utilized to offset the high initial cost of hydroponic infrastructure, or more basic hydroponic systems may gain traction.

While hydroponic lettuce farming could be more sustainable alternative to traditional lettuce farming practices at this time if it will depend on renewable energy, it does provide promising principles that might lead to more sustainable food production. In conclusion, hydroponic lettuce gardening is more efficient in terms of land and water use than conventional farming, and it has the potential to become a strategy for feeding the world's growing population sustainability if the high energy consumption can be reduced through improved efficiency and/or the use of cost-effective renewable.

Chapter 8

Conclusion and Future Work

8.1 Vertical Farming or Traditional Farming?

Vertical farming, a trend that has been gaining pace since 1999, demonstrates that there will always be new methods to boost food supply. With the world's population continuously rising, much attention is being focused on the contentious argument between vertical farming and traditional farming, and which will ultimately rescue humanity.

Vertical farming was one of the answers to this challenge. Variations of this strategy have been observed throughout history, but the potential wasn't completely realized until 1999, when a Columbia University professor filled out the concept. In 2001, once he figured out how to run a commercial vertical farm, the concept took off, and we're seeing it grow in popularity.

We are all familiar with traditional farming methods. We are aware of it, we comprehend it, and it is natural to us. The thought of producing our food in a warehouse with LED lights isn't particularly appealing, and it doesn't scream "fresh foods." Instead, many people imagine food created in a 'lab' as tasting bad.

Vertical farming is a solution to the unsolved problem of people flocking to cities in ever-increasing numbers. How will we feed them, and how will we provide them with fresh foods? To solve these problems, vertical farming employs two strategies. There is a wall-mounted system and a multi-layered system that incorporates many warehouse storeys.

8.2 Conclusion

The world's population is expected to increase from 7.8 billion in 2021 to 9.7 billion in 2050, assuming a 70 percent increase in agricultural production [1]. To attain this goal, an estimated 1 billion hectares of new land would be required if present farming practices are followed.

More than 80% of the world's arable land is now under use, and scientists estimated in 2015 that a third of the world's arable land has disappeared since 1975 [1]. It goes without saying that a backup plan is necessary. So vertical farming will be the best choice for the modern farming.

For city dwellers, vertical farming is the greatest option. It has the ability to supply food in a sustainable manner, so improving global food security and addressing environmental issues. A severe weather event would not cause a harvest to fail. It has the advantage of reducing the amount of cooling and heating water required by the interior temperature. It contributes to the reduction of poverty, the improvement of food security, and human well-being. Vertical gardening's effectiveness is determined by food demand and supply, urban population and densities, technical advancements, water and energy availability, and weather conditions.

Vertical farming is undoubtedly a solution to important difficulties in global agriculture, such as a lack of or overstock of agricultural products, excessive pesticide and fertilizer use, weakened soils, and even unemployment. As a result, vertical farming is the answer to decreasing arable land.

8.3 Future Work

Smart farming, as previously said, allows farmers to easily monitor and manage their crops and livestock from any device and from anywhere in the globe. Farmers are given specialized smart farming applications to help them do so. It may also be feasible to include data in these applications, depending on the program, making it even simpler for farmers to make informed decisions.

Many attempts have been made to maintain the agricultural fields, but all failed because of the huge cost and the high number of employees needed to accomplish the hard work. So this advanced research will solve this problem also because it will provide the farmer or company the tips and tasks that should be done in the suitable time before it becomes too late to avoid the damage of this field. This project contains many information in order to get best way of plantation treatment and better results. And these information will be inserted in future to a mobile application so that it's easy to anyone use it.

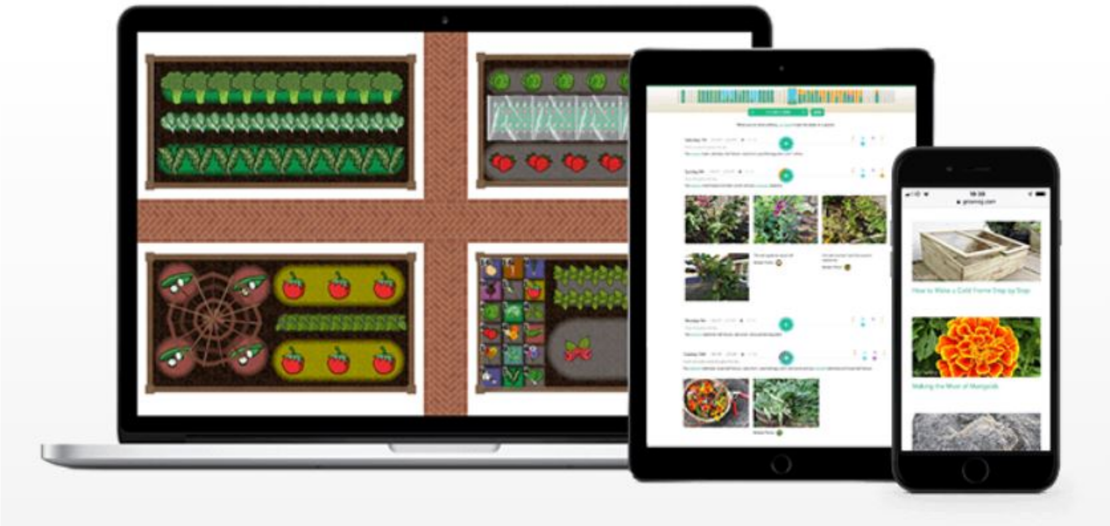


Figure 8.1: Mobile application as a future technology for agricultural monitoring system.

One more of the future technology that can serve the vertical farm is digital agriculture. The use of new and sophisticated technology, integrated into one system, to assist farmers and other stakeholders in the agricultural value chain to boost food production. The majority of today's farmers base their conclusions on a combination of imprecise measurements, expertise, and suggestions when deciding how much fertilizer to apply. After deciding on a plan of action, it is carried out, although the consequences are usually not visible until harvest.

On the other hand, a digital agricultural system collects data more often and correctly, and it is commonly coupled with data from other sources (such as weather information). The combined data is then analyzed and interpreted so that the farmer may make better-informed decisions. Robotics and modern technology can then swiftly apply these decisions with higher accuracy, and farmers may receive real-time feedback on the impact of their activities.

Figure 8.2: An example of digitalis application or website.

Web Bibliography

[1] *Smart Farming: How Automation Is Shaping the Future of Agriculture, by MICHELLE SCHLECHTRIEM, SEPTEMBER 6, 2021.* URL: https://www.meilirobots.com/resources-list/vertical-farming (cit. on pp. ii, 107).

[2] *A Look at the History of Vertical Farming, by Mark Crumpacker, Oct 19, 2018.* URL: https://medium.com/@MarkCrumpacker/a-look-at-the-history-of-vertical-farming (cit. on pp. 4, 5).

[3] *The origins of indoor vertical farming, by Vera Colstee, PlantLab, 23 AUGUST 2018.* URL: https://www.eitfood.eu/blog/post/the-origins-of-indoor-vertical-farming (cit. on p. 4).

[4] *Crops.* URL: https://www.nationalgeographic.org/encyclopedia/crop/ (cit. on p. 9).

[6] *Institute of Agriculture and Natural Resources, Tillage: Advantages and Disadvantages.* URL: https://cropwatch.unl.edu/tillage/advdisadv (cit. on p. 12).

[7] *Ohio State University, Using Cover Crops to Improve Soil and Water Quality, May 12, 2017.* URL: https://ohioline.osu.edu/factsheet/anr-57 (cit. on p. 14).

[8] *Conserve energy future, What is Crop Rotation?* URL: https://www.conserve-energy-future.com/advantages-disadvantages-crop-rotation (cit. on p. 16).

[9] *Advantages And Disadvantages Of Intercropping.* URL: https://agriinfo.in/advantages-and-disadvantages-of-intercropping-648/ (cit. on p. 17).

[10] *How does GM differ from conventional plant breeding?* URL: https://royalsociety.org/topics-policy/projects/gm-plants/how-does-gm-differ-from-conventional-plant-breeding/ (cit. on p. 20).

[11] *Madeline Kennedy, Evidence-based pros and cons of GMO foods, Nov 20, 2020.* URL: https://www.insider.com/gmo-pros-and-cons (cit. on p. 20).

[12] *Irrigation Scheduling*. URL: https://www.sherburneswcd.org/irrigation-scheduling (cit. on p. 22).

[13] *Advantages and Disadvantages of Sprinkler Irrigation System, Riyo, October 17, 2018*. URL: https://www.1001artificialplants.com/2018/10/17/10-advantages-and-disadvantages-of-sprinkler-irrigation-system/ (cit. on p. 23).

[14] *TYPES OF IRRIGATION – ITS 4 MAIN TYPES, ADVANTAGES DIS-ADVANTAGES, Engineer Ramiz, April 25, 2020*. URL: https://www.civilclick.com/types-of-irrigation/ (cit. on p. 24).

[15] *Advantages and Disadvantages of Dams, Nazmul Hassan*. URL: https://civiltoday.com/water-resource-engineering/dams/350-advantages-and-disadvantages-of-dams (cit. on p. 26).

[17] *The Disadvantages of Wetland Nature Reserves, November 22, 2019 By Maria Kielmas*. URL: https://sciencing.com/natural-resource-colorado-7611374 (cit. on p. 29).

[18] *Nutrient Management, Contributors:Julia Gaskin, University of Georgia, Athens, GA, Melony Wilson, University of Georgia, Athens, GA, June 12, 2009*. URL: http://soilquality.org/practices/nutrient_management (cit. on p. 31).

[19] *Nutrient Management, What is a Nutrient Management Plan?* URL: https://extension.usu.edu/agwastemanagement/Best-Management-Practices/nutrient-management (cit. on pp. 32, 33).

[20] *Nutrient Best Management Practices*. URL: https://www.missionrcd.org/nutrient-best-management-practices (cit. on p. 33).

[21] *Nutrient Best Management Practices*. URL: https://sustainagga.caes.uga.edu/management/nutrient-management (cit. on p. 34).

[23] *Advantages And Disadvantages Of Using Organic Fertilizer, By Kaitlyn Ersek on Apr 13, 2021*. URL: https://www.holganix.com/blog/8-advantages-and-disadvantages-of-using-organic-fertilizer (cit. on p. 36).

[24] *Advantages and Disadvantages of Composting*. URL: https://www.climate-policy-watcher.org/wastewater-sludge/advantages-and-disadvantages-of-composting (cit. on p. 37).

[25] *Crop protection*. URL: https://www.bbc.co.uk/bitesize/guides/zhktgwx/revision/4 (cit. on p. 39).

[26] *Green House vs Vertical Farm*. URL: https://www.agritecture.com/blog/2021/3/4/vertical-farms-vs-greenhouses-the-first-consideration-location (cit. on p. 41).

[27] *What Is Vertical Farming*. URL: https://www.edengreen.com/blog-collection/what-is-vertical-farming? (cit. on p. 41).

[28] *Hydroponics vs. Aquaponics vs Aeroponics: Common Features Differences, August 3, 2021 By Denisa*. URL: https://ponicsarea.com/hydroponics-vs-aquaponics-vs-aeroponics/ (cit. on pp. 42–46, 48).

[29] *Advantages Disadvantages of Hydroponics, February 10, 2022 by Trees.com Staff*. URL: https://www.trees.com/gardening-and-landscaping/advantages-disadvantages-of-hydroponics (cit. on p. 44).

[30] *What are the different types of vertical farming systems?* URL: https://attra.ncat.org/what-are-the-different-types-1/ (cit. on pp. 44, 46).

[31] *Vertical Farming Technology, by Matt, 2019*. URL: https://verticalfarmingplanet.com/vertical-farming-technology-how-does-it-work/ (cit. on pp. 49, 51–54, 56, 57).

[33] *Sanitization of Your Vertical Farming Cultivation Facility*. July 8, 2020. URL: https://pipphorticulture.com/grow-room-sanitation/ (cit. on p. 52).

[34] *Hydroponics in Vertical Farming, by Matt, 2019*. URL: https://verticalfarmingplanet.com/hydroponics-in-vertical-farming-what-is-it-and-how-it-works/ (cit. on p. 53).

[35] *Advantages Disadvantages of Vertical Farming*. URL: https://environmental-conscience.com/vertical-farming-pros-cons/ (cit. on p. 58).

[36] *How to grow Lettuce – Lettuce Complete Growing Guide from Seeding to Harvesting, by WIKIFARMER EDITORIAL TEAM*. URL: https://wikifarmer.com/how-to-grow-lettuce-lettuce-complete-growing-guide-from-seeding-to-harvesting/ (cit. on pp. 61, 63, 68).

[37] *Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods, by Guilherme Lages Barbosa, Francisca Daiane Almeida Gadelha, Natalya Kublik, Alan Proctor, Lucas Reichelm, Emily Weissinger, Gregory M. Wohlleb, and Rolf U. Halden, on June 12, 2015*. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4483736/ (cit. on pp. 98, 99, 102).

[38] *How iFarm vertical farms save water*. URL: https://ifarm.fi/blog/2020 (cit. on p. 100).

[39] *How Much Electricity Does a Vertical Farm Use*. URL: https://ifarm.fi/blog/2020 (cit. on p. 103).

Articles Bibliography

[16] Larry C. Brown Richard A. Cooke Gary R. Sands. «DRAINAGE WATER MANAGEMENT: A PRACTICE FOR REDUCING NITRATE LOADS FROM SUBSURFACE DRAINAGE SYSTEMS». In: () (cit. on p. 27).

[22] Angelica Galieni Michele Pisante Fabio Stagnari Albino Maggio. «Multiple benefits of legumes for agriculture sustainability». In: (2017) (cit. on p. 35).

[32] CEA Staff Dr. Melissa Brechner Dr. A.J. Both. «Cornell Controlled Environment Agriculture». In: () (cit. on pp. 50, 69–73, 75–77, 79–84, 86–89).

Books Bibliography

[5] The National Academies. *Toward Sustainable Agricultural Systems in the 21st Century*. 2010 (cit. on pp. 11, 15, 17, 18, 20–23, 25–29, 31, 32, 34–38).