2024 June

In The Field Of Agricultural Machinery And TECHNOLOGIES

Research And Evaluations

EDITOR
Prof. Dr. Ali Musa BOZDOĞAN

gece kitaplığı

İmtiyaz Sahibi • Yaşar Hız
Genel Yayın Yönetmeni • Eda Altunel
Yayına Hazırlayan • Gece Kitaplığı
Editor • Prof. Dr. Ali Musa BOZDOĞAN

Birinci Basım • Haziran 2024 / ANKARA

ISBN • 978-625-425-755-1

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İÇİNDEKİLER

BÖLÜM 1

SOILLESS AGRICULTURE AND APPLICATIONS

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Hydroponics is a soilless method of growing plants without soil, where plants receive nutrients through a nutrient-rich water solution. This cultivation technique has a history dating back to ancient civilizations, but modern hydroponics as we know it today has evolved significantly.

The concept of hydroponics has its roots in ancient civilizations, with the Hanging Gardens of Babylon often cited as an early example. Some ancient cultures, including the Aztecs and ancient Egyptians, used nutrient-rich water to grow plants. In the 17th century, the English scientist John Woodward conducted experiments that showed that plants could grow without soil if provided with water containing nutrients. In the 19th century, scientists such as Julius von Sachs conducted research on plant nutrition, contributing to the understanding of the essential elements that plants need to grow.

The term hydroponics originated in the 20th century. Hydroponic systems gained popularity in the 20th century as researchers and horticulturists developed various techniques for hydroponic cultivation.

Agricultural techniques used in controlled environments have become very important in recent years. The most important of these is “soilless agriculture”, which has come to the fore with the change in climatic conditions and the decrease in agricultural land. In recent years, this type of agricultural technique has been in high demand and many researches have been carried out in this field with the development of technology (Gül, 2018; Hossain et al., 2016).

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Agriculture 4.0, often referred to as the fourth agricultural revolution, is characterized by the integration of advanced technologies and data-driven approaches to improve the efficiency, sustainability and productivity of agriculture. Hydroponic farming methods are well suited to be integrated into Agriculture 4.0 practices. The integration of hydroponic techniques with Agriculture 4.0 technologies increases the precision, sustainability and productivity of hydroponic cultivation. By leveraging data, connectivity and automation, hydroponic systems can contribute to a more efficient and resilient agricultural system. In this context, the components of hydroponic farming technique; hydroponic system selection, growing medium selection, nutrient solution preparation, planting, providing light, monitoring and adjusting pH and EC, nutrient solution circulation, aeration, harvesting, maintenance and cleaning and aquaponic farming technique and its components; fish tank (aquaculture), biological filter, growing bed (hydroponics), plants and nutrient uptake and water return to the aquarium are explained. In addition to these topics, symbiosis and nitrogen cycling are summarized.

The farming methods used today depend on many factors. Especially in traditional cultivation, soil nutrients may be insufficient and soil structure may not be suitable for agriculture. The presence of pests and diseases in the soil significantly reduces yield. For this reason, most of the problems encountered in field conditions can be easily overcome in cultivation with soilless farming techniques. It is reported that the yield increase obtained with soilless farming techniques is 4 to 10 times higher than traditional methods. The most efficient method is to use hydroponic farming techniques in greenhouse conditions. The easiest crops to grow in this way are tomatoes, cucumbers, peppers, lettuce and other leafy vegetables and herbs (Despommier, 2009).

The major disadvantage of soilless farming techniques is the cost and know-how required during the initial set-up phase; some diseases caused by organisms such as Fusarium and Verticillium wilt can spread rapidly throughout the system. These problems can usually be overcome by the use of disease-resistant varieties and testing equipment. The most important advantages are the application of non-arable land and efficient use of water and fertilizer (Satici, 2010).

Today, about 12% of the world's land (1.5 billion hectares) is used for agricultural production. According to the FAO 2030/2050 forecast report, the per capita arable land area in the world will decrease year by year, both in developing and developed countries. While the world population and food demand continue to grow, the per capita arable land area is decreasing year by year, indicating that countries will face a food crisis in the next few years. Moreover, while the world's arable land is decreasing due to climate change and the use of agricultural land for non-agricultural purposes, the world population is growing faster than ever before. Whereas 100 years ago it took 20 years for the world population to increase by 100 million people, the world population increased by 83.3 million in 2018 alone (FAO, 2019).

Today, cross-border agricultural investment and soilless farming methods have become the solution. In addition to the decrease in arable land, the decline and pollution of freshwater resources are other major problems facing agriculture. In today's world, the struggle to obtain water is increasing rapidly and the amount of water used in traditional agricultural methods is becoming uneconomical. Closed system soilless farming techniques that use water efficiently are rapidly gaining importance today. While global water consumption was around 1 km^3 per year in the 1940s, this figure doubled in the 1960s. In the 1990s, water consumption reached 4 km^3 $year^{-1}$ (Gülgönül & Akiş, 2020).

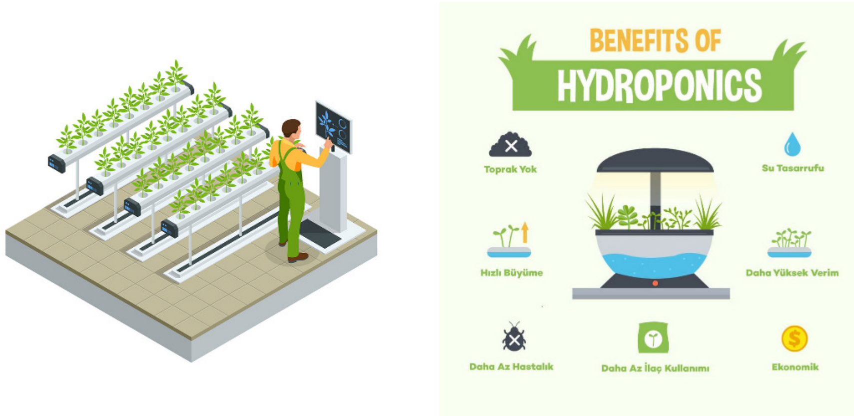

Figure 1. Different ways of cultivation using soilless farming techniques (Reifsera, 2024)

Parameters of Hydroponic Agriculture

1. Growing Environment:

Hydroponic systems use an inert growing medium to support plant roots.

The growing medium provides physical support for the plants and helps stabilize the roots. Common growing media include perlite, vermiculite, coco fiber, rock wool and others. These media do not contain nutrients but provide good aeration and water retention.

2. Nutrient Solution:

Plants in hydroponic systems receive essential nutrients directly through a water-based solution.

The nutrient solution contains a carefully balanced mixture of macro- and micronutrients essential for plant growth. Essential nutrients include nitrogen, phosphorus, potassium, calcium, magnesium and various trace elements. The composition of the solution can be adjusted according to the specific needs of the cultivated plants.

3. Water and Nutrient Circulation:

Hydroponic systems involve continuous or periodic circulation of nutrient solution.

Different hydroponic systems use various methods to circulate the nutrient solution, such as drip irrigation, nutrient film techniques (NFT), aeroponics or deep water culture. Circulation ensures that plants receive a consistent supply of water and nutrients, promoting optimal growth.

4. Controlled Environment:

Hydroponics allows precise control of environmental factors.

Controlled environment agriculture involves managing temperature, humidity, light intensity and photoperiod to create optimal conditions for plant growth. Greenhouses and indoor farming facilities provide the ability to manipulate these factors, maximizing the efficiency of nutrient uptake and promoting faster, controlled growth.

5. pH and EC Management:

pH, the acidity or alkalinity of the solution, and electrical conductivity (EC) are monitored and adjusted in hydroponic systems. pH is a value between 0 and 14, with a value of 7 representing neutrality. Values below 7 indicate increasing acidity towards zero and values above 7 indicate increasing alkalinity towards 14.

Maintaining the correct pH level (typically slightly acidic for most plants) is crucial for nutrient availability. EC measurement indicates the concentration of nutrients in the solution. Regular monitoring and adjustments ensure that plants receive the right balance of nutrients for optimal growth.

6. Ventilation:

Proper ventilation is essential for oxygen supply to the plant roots.

In hydroponics, ensuring adequate oxygen supply to the root zone is essential for plant health. Aeration can be achieved through the design of the hydroponic system, including the use of air stones, diffusers or other mechanisms that supply oxygen to the nutrient solution.

Hydroponic systems offer advantages such as water efficiency, precise nutrient control and the ability to grow crops in non-arable or limited space environments. The choice of a specific hydroponic system depends on factors such as the type of plant, available space and the level of automation desired by growers. As technology advances, there are constant innovations in hydroponic techniques, making it an increasingly popular cultivation method in modern agriculture.

Components of Hydroponics Agriculture Technique

1. Hydroponic System Selection:

Nutrient Film Technique:

In NFT, a thin film of nutrient solution flows over a sloping channel and plant roots are exposed to the solution as it flows down the channel. The roots take up the nutrients and excess solution is collected for recirculation.

Deep Water Culture:

Plants are suspended in a nutrient-rich water solution, usually in containers or troughs. Air stones or diffusers are used to supply oxygen to the roots. DSK is simple but effective for many plants.

Drip Irrigation Systems: In drip irrigation systems, a pump delivers a controlled amount of nutrient solution to each plant through a network of tubes and emitters. This method is versatile and widely used for a variety of crops.

Aeroponics:

Aeroponic systems keep the plant roots suspended in the air and the nutrient solution is delivered as a fine mist. This method provides high oxygen levels to the roots, promoting rapid growth.

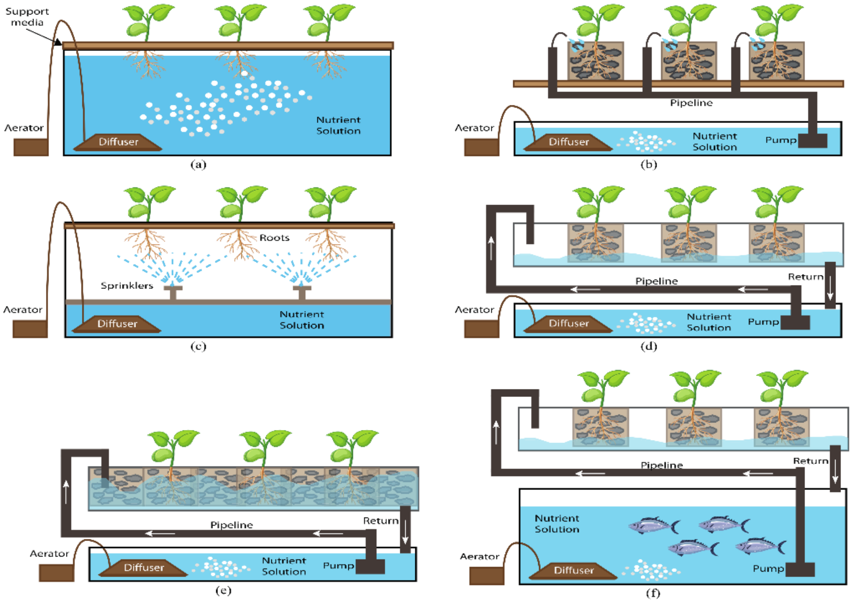

Figure 2. *Hydroponic farming techniques (Velazquez-Gonzalez et. al., 2022)*

2. Selection of Growing Environment:

The choice of growing medium depends on the hydroponic system and the specific needs of the plants. Common media include:

Perlite Light volcanic rock.

Perlite is a natural glassy rock formed as a result of the contact of acidic molten magma with water or steam under high pressure as a result of volcanic activities. The biggest difference that distinguishes perlite from other glassy rocks is the high proportion of water in its composition. Perlite, which is silver gray or black in its natural state, is fine-grained, porous, loose, easily breakable.

In the preparation of plant growing media, inorganic materials such as pumice, perlite, volcanic ash and organic materials such as coccopite, peat and sawdust are applied directly or indirectly to the soil in order to improve the physical, chemical and biological properties of the media. These materials can be used individually or in mixtures as plant growing media. Today, in addition to solid media cultures, liquid media are also used in plant production as an alternative, especially in greenhouse cultivation (Hickman, 2011; Burrage, 1992, Satici, 2010).

Vermiculite Expanded minerals that retain water.

What is vermiculite? It is a mica-like mineral that acts as a soil conditioner. It is mined from underground and curled together with high heat. Because of its worm-like, twisted appearance, its name comes from the Latin vermiculus, which means "insect larva".

After heating, it not only curls, but also expands and sterilizes. Both of these properties are important for plant cultivation.

It is silvery gray and flaky. It is very light, you can even move small particles by blowing on them. The product does not contain any fertilizer, so you need to mix it with something that provides nutrients (such as compost) if you are not going to apply fertilizer periodically (Hickman, 2011; Burrage, 1992, Satici, 2010).

Kokopit: Fibrous material derived from coconut shells.

Kokopite or coco fiber is a type of fiber derived from the fibrous layer covering the coconut fruit. With increasing environmental pressure on greenhouse operations to use sustainable or renewable resources, the use of compressed peat culture is spreading rapidly. Many large hydroponic greenhouse projects in Canada, the United States, and Mexico are choosing compressed peat culture as their preferred substrate (Gunn, 2004; Lindhout, 2010; Schineller, 2009).

Stone Wool Spun mineral fibers with excellent water retention.

In the last 30 years, rockwool culture has been used to grow grapes, especially tomatoes, cucumbers and peppers. In Denmark, rockwool began commercial production in 1937 in cooperation with the Rockwool Group. In 1949, rock wool began to be produced in the Netherlands. Grodan, founded in 1969 as a subsidiary of the Rockwool Group, started producing rock wool for horticulture in the Netherlands in 1979. Grodan now operates in more than 60 countries worldwide (Graves, 1986). In 1978, the total area of tomato production in the UK using rock wool was less than 1 hectare. This increased to 77.5, 126 and 148 hectares in 1984, 1985 and 1986 respectively. Similarly, the area of rockwool culture for cucumber production increased from 1 hectare to 68 hectares in the period 1978-1986. In 1991, Desmond Day estimated the UK's estimated use of rockwool culture at 230 hectares for cucumbers and 160 hectares for tomatoes. Rockwool culture is now the most widely used form of hydroponics in the world, with over 2000 hectares of greenhouse crops grown in the Netherlands using this system. Rock wool is made from basalt (solid lava) melted in a furnace at 1500 °C. At 230 °C it is hardened in a furnace using hot air, compressed and cut. The reason for the rapid growth of the greenhouse industry in the last 15 years is related to the rock wool culture. However, for the last decade, rock wool has been reportedly not destroying in landfills and there have been concerns about its disposal. Many producers are now looking for alternative substrates in the form of natural, environmentally friendly and sustainable coir (Graves, 1986).

3. Preparation of Nutrient Solution:

The nutrient solution is prepared by dissolving certain hydroponic grade fertilizers in water. The solution contains essential nutrients including nitrogen, phosphorus, potassium, calcium, magnesium and micronutrients. The concentration is adjusted according to the growth stage and plant type.

4. Planting:

Seeds or seedlings are planted in the growing medium. Care is taken to space the roots appropriately to facilitate contact with the nutrient solution.

5. Providing Light:

Hydroponic systems are often used in combination with artificial lighting, especially in indoor environments. Full spectrum lighting, such as HPS (High pressure sodium) or LED bulbs, provides the light required for photosynthesis. Light intensity, duration and spectrum can be controlled to optimize plant growth.

6. Monitoring and Adjustment of pH and EC:

Regular monitoring of the pH level is essential to maintain nutrient availability. EC measurement helps to ensure the correct nutrient concentration. Adjustments are made by adding pH regulators or changing the composition of the nutrient solution.

7. Circulation of the nutrient solution:

The nutrient solution is circulated using pumps, pipes and distribution systems specific to the chosen hydroponic method. Circulation provides plants with a constant supply of water and nutrients, promoting efficient nutrient uptake.

8. Ventilation:

Adequate aeration is crucial for root health. Systems such as deep water culture use air stones or diffusers to add oxygen to the nutrient solution. In aeroponics, roots are exposed to oxygen-rich air by misting them with the nutrient solution.

9. Harvest:

Harvesting depends on the type of crop. Leafy greens can be harvested as they mature, while fruit-bearing crops are harvested when the fruits reach the desired size and ripeness. Harvesting techniques are adapted to each type of plant.

10. Maintenance and Cleaning:

Regular maintenance includes checking nutrient levels, cleaning components and ensuring system health. Maintaining cleanliness helps prevent the build-up of algae or pathogens that can negatively affect plant growth.

Hydroponic farming provides a controlled environment for plant growth, allowing efficient nutrient utilization, reduced water consumption and year-round cultivation. Success in hydroponics often requires careful monitoring, adjustments to plant needs and attention to the cleanliness and functionality of the system.

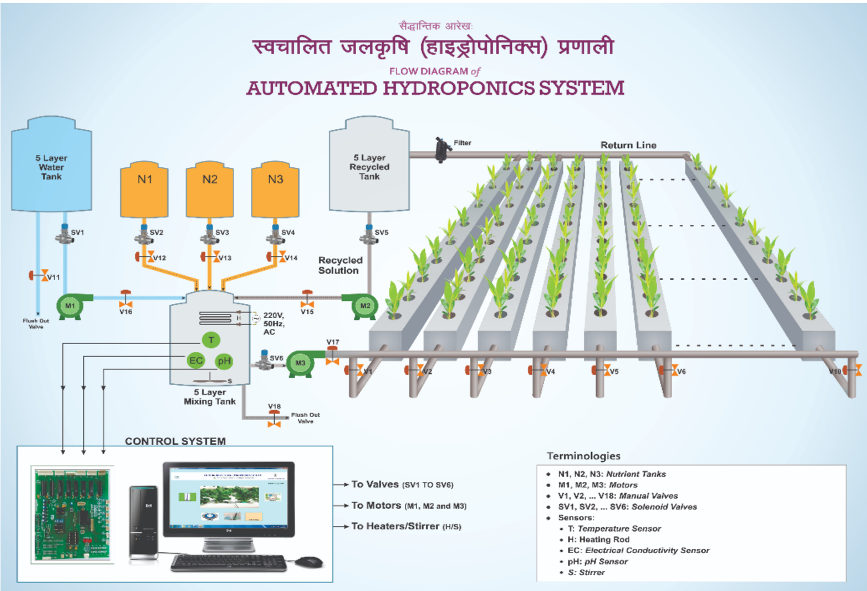

Figure 3. *Hydroponics and automation (CDAC, 2024)*

Aquaponic Agriculture Technique and Components

Aquaponics is a sustainable and integrated agricultural system that combines aquaculture (raising fish) and hydroponics (growing plants without soil). It creates a mutually beneficial environment where fish waste provides nutrients for plants and plants help filter and purify water for fish. This closed loop system is designed to be efficient, environmentally friendly and resource conserving.

Aquaponics generally works like this:

Let's examine the main components and processes involved in aquaponics:

1. Fish Tank (Aquaculture): This is where the fish are raised. The type of fish chosen depends on the design of the system and environmental conditions. Common choices include tilapia, catfish, trout or other freshwater species. Fish produce waste through their feces and gills, primarily in the form of ammonia.
2. Biological Filter: In an aquaponic system, a biological filter is installed to convert the toxic ammonia produced by fish waste into less harmful substances. Beneficial bacteria play a very important role in this process. These bacteria convert ammonia into nitrites and then nitrates. Nitrate is a form of nitrogen that serves as food for plants.
3. Growing Bed (Hydroponics): Nutrient-rich water containing nitrates is pumped or circulated into a grow bed where plants are grown. The plants in the grow bed can be a variety of vegetables, herbs or other crops. Instead of soil, these plants are grown using a hydroponic system where their roots are directly exposed to nutrient-rich water.
4. Plants and Nutrient Intake: Plants effectively filter and purify water by absorbing nitrates and other nutrients from the water. This process not only benefits the plants, but also removes excess nutrients, providing a healthy environment for the fish.
5. Return of Water to the Aquarium: After the water has been filtered by the plants, it is returned to the aquarium. As the fish continue to produce waste, the cycle repeats and the system maintains the balance between fish, bacteria and plants.

This closed-loop system creates a sustainable and efficient way to produce both fish and plants. The fish provide food for the plants and the plants help maintain water quality for the fish. Aquaponic systems are known for their resource efficiency, as they generally use less water than traditional soil-based agriculture and can be applied in a variety of settings, including urban environments and controlled indoor spaces such as greenhouses.

This symbiotic relationship between fish and plants creates a closed system that can be operated with minimal water use compared to traditional soil-based agriculture. Aquaponic systems are often used in controlled environments such as greenhouses and make it possible to grow a variety of crops year-round. This method of farming is popular among those looking for sustainable and efficient ways to produce both fish and plants for food (Bartelme et al., 2018; Diver, 2006).

Symbiosis and the nitrogen cycle

Symbiosis is a very important concept for aquaponic systems. Symbiosis can be considered as a life cycle that supports the whole ecosystem. The concept of symbiosis is the phenomenon of two or more species sustaining or supporting their lives by benefiting from each other. In aquaponics, symbiosis is mainly a cycle between microflora, plants and fish. The concept of "symbiosis", which is defined as the coexistence of different species of living things under the condition of mutual benefit from each other, has been used in different sectors in recent years and is called "Symbiosis Industrial Ecology". The common use of energy, raw materials, manpower, water and similar resources is as important as the utilization of products and wastes resulting from production. All outputs other than products are utilized in other systems within or outside the system (Fazio and Jannelli, 2006).

The nitrogen cycle starts with the breakdown of ammonia produced by fish using oxygen by bacteria called nitrosomonas. At the end of this chemical process, nitrosomonas bacteria convert the ammonia in the water into nitrite. Nitrite is a compound that is as harmful as ammonia and must be removed from the water. At this stage, another type of bacteria, nitrobacter, comes into play and breaks down nitrite to form nitrate. Nitrate acts as a fertilizer for plants. By using this fertilizer, plants both purify the water and continue their development by taking the nitrogen they need for themselves (Fazio and Jannelli, 2006; Kaspar et al., 1985).

Automation Applications in Hydroponic Agriculture

Hydroponic agriculture has made significant progress with the integration of agriculture 4.0, automation, industry 4.0 technologies and sensor applications. Some examples can be summarized as follows.

1. Automated Nutrient Delivery Systems: Automated nutrient delivery systems precisely control the pH and nutrient levels in the water solution used to feed plants. These systems can adjust the nutrient concentration based on real-time data collected from sensors that monitor the plant's growth stage, environmental conditions and nutrient uptake.
2. IoT-powered Environmental Monitoring: Industry 4.0 technologies such as Internet of Things (IoT) devices are used to monitor environmental factors crucial for plant growth, such as temperature, humidity, light intensity and CO2 levels. Sensors placed th-

roughout the growing area collect data, which is then analyzed to optimize growing conditions and detect anomalies or deviations that could affect plant health.

3. Automatic Climate Control Systems: Climate control systems automatically adjust environmental conditions in the growing area to maintain optimal parameters for plant growth. These systems can include automatic ventilation, heating, cooling and shading mechanisms controlled by sensors and actuators. They ensure consistent conditions throughout the year, regardless of outside weather fluctuations.

4. Remote Monitoring and Control: Farmers can remotely monitor and control various aspects of their hydroponics setup using mobile apps or web-based platforms. This allows them to check real-time data, receive alerts or notifications, and adjust system parameters as needed, providing flexibility and ease in managing their operations.

5. Robotics for Crop Care: Robotic systems are used in hydroponic farming setups for tasks such as seeding, planting, pruning and harvesting. These robots can be equipped with vision systems to identify and selectively target plants for specific actions, reducing labor costs and increasing productivity.

6. Data Analytics for Predictive Maintenance: Industry 4.0 principles include leveraging data analytics and predictive maintenance techniques to identify potential equipment failures or maintenance needs before they occur. By analyzing data collected from sensors embedded in irrigation systems, nutrient delivery systems and other equipment, farmers can proactively schedule maintenance, minimize downtime and optimize system performance.

7. Automated Irrigation Systems: Sensor-based irrigation systems ensure efficient water use by delivering precise amounts of water directly to plant roots based on soil moisture levels, weather conditions and plant requirements. These systems help save water, prevent overwatering or flooding and reduce the risk of nutrient leaching.

8. Smart Greenhouse Management: Smart greenhouse technologies integrate automation, sensors and control systems to optimize growing conditions and maximize crop yields. This includes automated shading, light supplementation, CO_2 enrichment and irrigation management based on real-time data and predictive algorithms.

By integrating automation, Industry 4.0 and sensor applications into hydroponic farming systems, farmers can achieve higher yields, improved resource efficiency, reduced labor costs and greater control over crop quality and consistency.

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BÖLÜM 2

COMPONENTS OF AUTOMATION APPLICATIONS IN SOILLESS AGRICULTURE

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1. Introduction

Soilless agriculture is a rapidly expanding modern agricultural technique that allows plants to be grown in nutrient solutions instead of soil. This method offers great advantages, especially in areas with dense urbanization and limited agricultural land. The use of automation systems plays an important role in increasing productivity and sustainability in soilless agriculture.

Automation applications make use of various technologies such as sensors, actuators, control units and software to optimize plant growth and productivity in soilless agriculture. Sensors continuously monitor the pH and EC of nutrient solutions, water level, and environmental conditions such as temperature and humidity. This data is transmitted to a central control unit and analyzed.

Automation systems can adjust the composition of nutrient solutions, optimize irrigation frequency and regulate the climatic conditions in the growing environment in line with the data obtained. In this way, the optimum growth conditions required by the plants are provided, productivity is increased and savings are achieved.

In this study, the components of automation systems used in soilless agriculture are introduced in general. Some examples of these components are examined and their interfaces and operating principles of the systems are explained.

2. Soilless Production Systems

Soilless agriculture is divided into two main groups: “water culture” and “substrate culture”. Water culture is classified into different subcategories depending on the application of the nutrient solution. Plant roots grow in the nutrient solution (standing water culture) or the nutrient solution flows along the plant roots (flowing water culture) or the nutrient solution is applied to the plant roots as a mist (aeroponics). In substrate culture, plants are grown in organic, inorganic or synthetic materials. These materials provide an environment where the roots can hold on and usually nutrient solution is used to meet the water and nutrient needs of the plants (Ünal, 2020 and Dayıoğlu, 2019).

2.1 Water Culture

2.1.1 Ditch-Water Culture

It is the oldest soilless production technique and is currently only used in plant nutrition studies. One of the most important advantages of this system is that there is no drip irrigation system or spray emitters that can clog.

Ditch-water culture can be done with or without aeration. In the non-aerated method, the nutrient solution is placed in light-tight, approximately 15 cm deep containers. The top of the containers is covered with a light-proof material to keep the plants standing (Figure 1a). The level of the nutrient solution is periodically checked and the missing amount is replenished; the solution should also be changed at intervals of 7-14 days depending on the growth period of the plant. In the aerated method, an aeration pump is added to the non-aerated still water culture containers and the plant roots are directly aerated using an air stone (Figure 1). Regular monitoring of oxygen and nutrient concentrations, salinity and pH levels are mandatory. Because algae and molds can grow rapidly in the reservoir (Domingues et al., 2012).

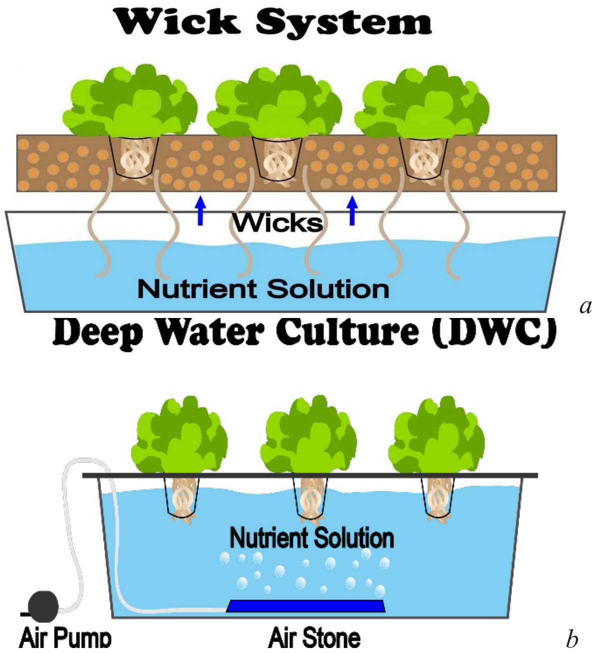

Figure 1. Ditch-water culture (Anonymous a, 2024)

2.1.2 Flowing Water Culture

The basic principle of this method is to ensure adequate water, nutrients and aeration by circulating a thin layer (less than 1 cm) of nutrient solution along the roots of the plants (Figure 2). In this method, nutrient solution is pumped continuously or intermittently along the channels where the plants are placed (Domingues et al., 2012). When the nutrient solutions reach the end of the canal, they are returned to the nutrient tank. The channels should be placed at a slope of at least 1/100 so that the nutrient solution can flow due to gravity. In intermittent applications, the solution flow is programmed by a timer or solar radiation value. The use of a timer is a simple and economical method. At set time intervals, the pump runs for a certain period of time. It is possible to place the channels directly on the greenhouse floor or on a frame.

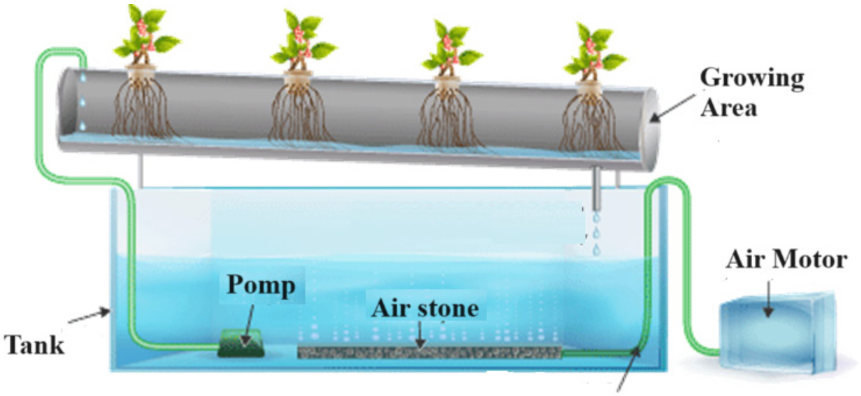

Figure 2 Flowing water culture (Anonymous b, 2024)

Tiered flowing water culture systems can be installed to increase the number of plants per unit area. These systems can be used for commercial production of salad, lettuce, strawberries, etc., and for hobby vegetable or ornamental plant cultivation in homes and offices.

2.1.3 Aeroponics

In this method, nutrient solutions are applied continuously or intermittently to the bare plant roots as mist or vapor. Therefore, the problem of decreasing oxygen content of the solution is not encountered (Figure 3). This technique requires a light-tight container, a nutrient solution tank and a spraying system. This system provides faster growth of plants due to the high oxygen level in the growing medium; it also saves water and fertilizer compared to other soilless methods.

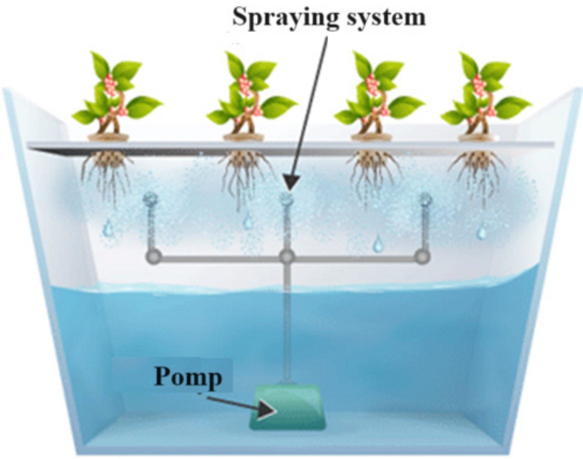

Figure 3. Aeroponics (Anonymous c, 2024)

2.2 Substrate Culture

Substrate culture is more widely preferred in commercial plant cultivation because water culture systems require more elaborate technical equipment and uninterrupted electrical energy, and that the temperature of the nutrient solution in the summer months in hot regions exceeds 35°C, causing some disease agents to multiply in the solution and ultimately leading to the death of the roots. (Dayıoğlu, 2019)

Substrates are divided into two parts: "inert substrates" and "non-inert substrates". Inert substrates do not react chemically, they are inert. That is, they do not react with the nutrient solution. For example, inorganic materials (clump, perlite, volcanic tuff, gravel, rock wool...). Non-inert substrates are chemically active. This means that they can retain nutrients or release nutrients into the environment. For example, organic materials such as peat, sawdust, bark and coconut peat can be used. (Ünal, 2020)

Substrate culture cultivation is generally practiced by the following four methods;

- Cultivation in beds
- Cultivation in pots
- Growing in bags
- Cultivation in vertical bags

3. What is automation?

The word automation was first used in 1940 by S. Harder, vice president of Ford Motor Company, and means self-movement (Anonymous, 2017).

Especially for the manufacture of products in the industrial sector, until the 1970s the term referred to technologies that enabled specific tasks to be performed by machines. However with the advent of computers, the tasks and functions of automation have expanded. From part and product design to communication management and information exchange (Anonymous, 2017).

Automation is defined as "automated working technologies integrated into a set of operations in which processes involving product handling, design and manufacturing processes are carried out without human intervention" (De Coster, 1999).

3.1 Types of System Control

The controller is used as a decision-maker in the management of the process. The tasks of the controller can be defined and used to derive different forms of control. There are two types of system control; **open-loop control** and **closed-loop control**.

3.1.1 Open Loop (No Feedback) Control System

These are systems that are not affected by the output of the system and are controlled only by devices that perform the control process according to the specified reference value. This control method is used in systems that do not require precision. Detection of disturbing factors affecting the system can be done by humans (Çağlayan, 2023 and Dayıoğlu, 2019).

The control element takes the given reference signal and generates a control signal. When this signal is applied to the controlled system, the system regulates the input variable and provides the desired output signal. Open loop control is generally used in applications where the structure of the controlled system and the other inputs acting on the system are well-known in advance.

3.1.2 Closed Loop (Feedback) Control System

These are systems in which the difference between the reference and output signals is automatically eliminated after the reference value at the input is compared with the output value from a controlled system. Closed loop is also called feedback loop.

3.2 Components Used in Automation Systems

Automation systems consist of various components, such as hardware and software systems, which are combined to manage and automate as much as possible a specific process, procedure or operation (Bouchareb, 2023). Some components used in automation systems are described as follows.

3.2.1 Control Unit

This unit, which functions as the brain of automation systems, can often be a PLC (Programmable Logic Controller). The control unit is programmed to manage and coordinate the automation process (Bouchareb, 2023). Figure 4 shows an example schematic of a control unit.

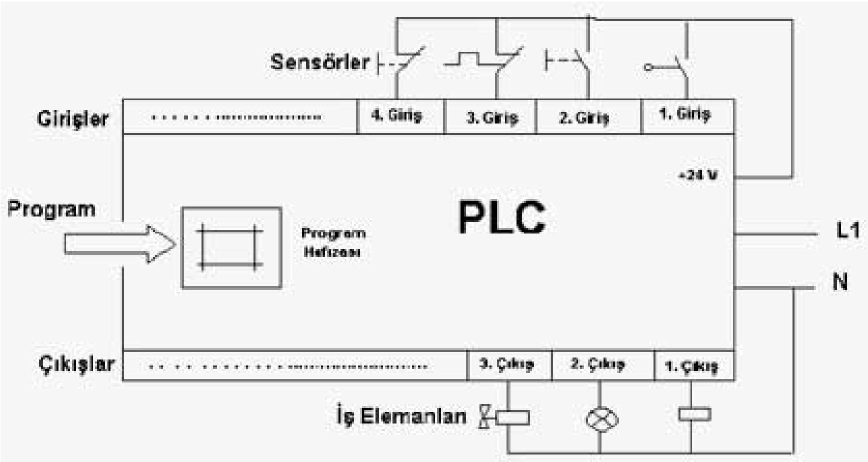

Figure 4. Control unit (Anonymous d, 2024)

A programmable logic controller (PLC) is a special computer device used in industrial control systems that perform a single task, usually without a monitor, keyboard or mouse. Thanks to its rugged construction, it is designed to withstand harsh industrial environments such as extreme temperatures, strong vibrations, humidity and electrical noise. With its outstanding functional features such as sequential control, counters and timers, easy programmability, reliable control capabilities and easy handling of hardware, this PLC is used as a specialized computer in industries and other control system fields (Bouchareb, 2023 and Dayıoğlu, 2019).

3.2.2 Sensors

In many fields (such as industry, scientific research and agriculture), there is a need to control physical quantities (temperature, humidity, position, speed, light, etc.). When a physical quantity is to be converted into another quantity (usually an electrical quantity), devices called "sensors" are used (Sadi, 2019).

Sensors are elements that can perform sensing and electrical conversion together. The electrical signals converted by the sensor are processed and transferred to the display. In this process, signal processing, filtering, amplification and digitalization are applied. The main processor of the circuit ensures that the converted signal is displayed and transmitted (Dayıoğlu, 2019).

3.2.2.2.2 Temperature Sensors

Temperature measurement is based on the detection of new conditions resulting from heat transfer in the process. Therefore, appropriate process-specific sensors need to be used (Figure 5). Two types of temperature sensors are used in industry: contact and non-contact. There are five types of the most commonly used contact type sensors (Dayıoğlu, 2019):

1.Resistance type temperature detector (RTD),

2. Thermistor,

3.Thermocouple (thermocouple).

4. Analog sensor,

5. Digital sensor

Figure 5. Contact-type temperature sensors (Dayıoğlu, 2019)

3.2.2.3 Humidity sensors

Humidity sensors are elements designed to measure and monitor the moisture content or relative humidity (RH) in the surrounding environment, detecting water vapor in the air and providing an output signal associated with the humidity level (Anonymous h, 2024).

The methods used in the measurement of relative humidity are as follows:

- Hygrometer,
- Wet and dry thermometer (psychrometer),
- Resistance type sensors,
- Capacitive sensors (Dayıoğlu, 2019)

3.2.2.4 CO_2 sensor

Some chemical substances have the ability to absorb infrared radiation at certain wavelengths. CO_2 gas absorbs infrared radiation at a wavelength of 4.26 µm. The transmittance of radiation through the sampled gas decreases as the concentration of CO_2 increases. The concentration of the gas is directly proportional to the amount of absorbed radiation (Dayıoğlu, 2019).

Three methods are generally used to measure gas concentration:

1. Optical waveguide-free infrared ray analyzer (DIR),
2. Optical waveguided infrared absorption (NDIR),
3. Fiber optic beam steering.

3.2.2.5 Electrical Conductivity (EC) - pH - Flow Sensors

Since a large amount of water and fertilizers are used in soilless production, it is necessary to know the pH and EC levels of irrigation water quality in the growing medium (substrate) stages in the plant root zone before reaching the plants. pH is the hydrogen ion concentration in water, while EC indicates the amount of dissolved minerals. Depending on the plant produced, it is important to keep the pH and EC in the ranges of 5.4-6.2 and 2-5 mS/cm, respectively, to ensure the absorption of all nutrients in soilless agriculture.

The pH and EC sensors, which can be mounted on the line, are sensors that provide electrical signal output suitable for automation systems (Figure 6). These sensors are the most important measurement elements of the fertigation system. Fertigation machines operate according to the data received from pH and EC sensors in the irrigation line. In addition, salt accumulation in the plant root zone is measured periodically with substrate-type EC sensors. (Dayıoğlu, 2019)

Figure 6. In-line sensors installed on the pipe (Dayıoğlu, 2019)

3.2.2.6 Irradiance Sensors

Three different measuring devices can be used to measure solar radiation: Total radiation meter (310-2800 nm, 0-2000 W/m^2 ±5%, 10 µV/ Wm^{-2}), Total radiation meter (400-1100 nm, 0-1750 W/m^2 ±5%, 1 mV/ Wm^{-2}), PAR meter (Quantum sensor: 400-700 nm, 0-2000±5%, 1 mV/µmolm^{-2} s^{-1}) (Figure 7).

Figure 7. Different solar radiation measurement devices (Dayıoğlu, 2019)

3.2.3 Actuators:

Actuators are components that set machine parts in motion as a result of electrical commands. This is done by converting an input energy (electrical, hydraulic or pneumatic) into an output energy (mechanical) (Bouadi, 2023).

3.2.3.1 Electric Actuators

Electric actuators are essentially electric motors, which are devices that convert electrical energy into mechanical energy. Their working principles are based on the principles of electromagnetism. Motors consist of two parts, the stator (fixed) and the rotor (moving) (Bouadi, 2023).

3.2.3.2 Hydraulic Actuators

Hydraulic actuators use various fluids as energy sources (Figure 8). In the beginning, water was used as a fluid. However, due to the freezing and corrosion of water at certain temperatures, oils are mostly used for this purpose today. The oils used in this context are called hydraulic oils. Hydraulic actuators can be used in systems that provide both linear and circular motion (Bayraktar et al., 2023).

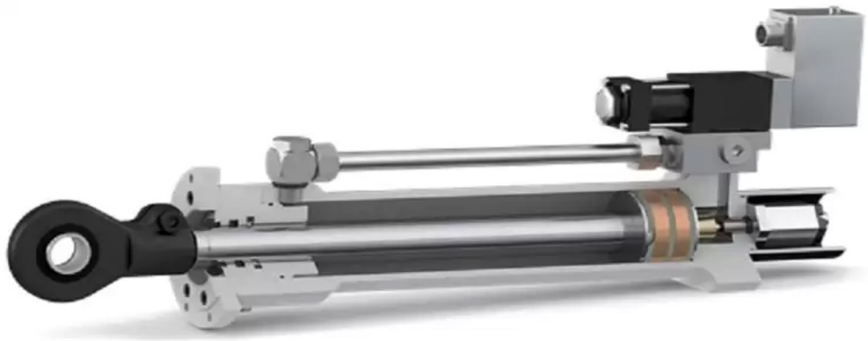

Figure 8. Hydraulic Actuator (Anonymous e, 2024)

3.2.3.3.3 Pneumatic Actuators

Pneumatic actuators convert gas pressure into motion (Figure 9). For this purpose, air can be used or other gases can be utilized. These types of actuators are used to provide linear or circular motion just like hydraulic actuators (Bayraktar et al., 2023).

Figure 9. Quarter turn pneumatic actuator valve (Anonymous f, 2024)

3.2.4 Data Communication Networks

Data collection, processing and analysis processes between systems are carried out by automation systems communicating with PLC and computer systems. To ensure that the communication between the transmitter and receiver is fast and reliable, certain rules must be defined according to the devices used. By defining these rules, communication protocols are also defined. Among the most commonly used communication protocols; **Fieldbus, Modbus, Profibus, As-i, Canbus, Ethernet, Profinet, CANopen** protocols are included.

3.2.4.1 Fieldbus Protocol

A fieldbus is a field network of automation devices and computers (Figure 10). Offering high resolution measurement and high reliability, the Fieldbus is also capable of self-testing. Rounding loss is not an issue in this protocol. It is a protocol with a significant market share due to its multifunctional field units. It enables PLC systems to communicate with each other with the loops it establishes.

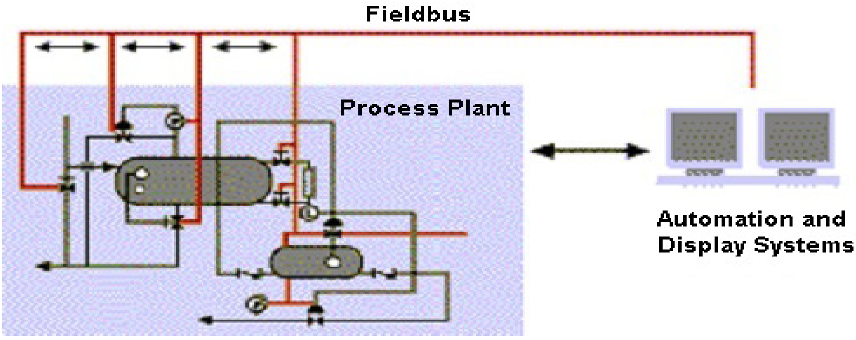

Figure 10. Fieldbus protocol application diagram

3.2.4.2 Modbus Protocol

Modbus is the most widely used communication protocol in industry thanks to its simple and powerful structure. It works using a master-slave structure. The master device (master information client) sends data requests to the slave devices (slave devices) (Figure 11). This protocol is used for data read and write operations. There are different variants of Modbus. Such as Modbus RTU (serial port) and Modbus ASCII (serial port).

Modbus uses RS232 serial communication standard for short distance connections and RS485 serial communication standard for long connections. In this protocol, data is transmitted in bits consisting of 1s and 0s.

Highly flexible, Modbus can be used to communicate between sensors and other devices or to control devices in the field remotely via a computer.

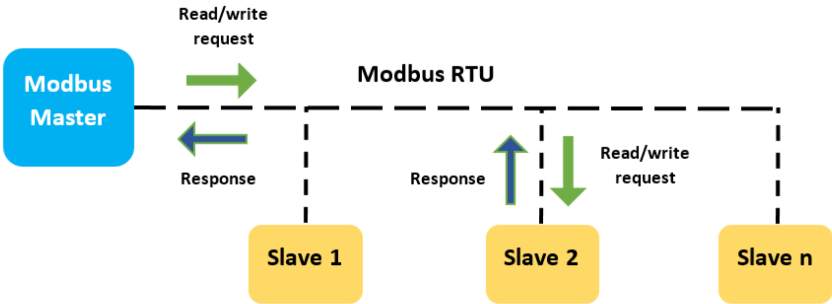

Figure 11. Modbus RTU (Anonymous g, 2024)

3.2.5 Programming Software

Software is used to program and configure automation systems. This software allows defining functions, configuring sensors and actuators and creating control strategies. Some commercial automation software used in Turkey are Hoogendorn iSii, Priva INTEGRO, Priva Office, Inta (Air Conditioning) EVO AP , Inta (Irrigation) CDN , Karaca KRSS.

3.2.5.1 Hoogendorn

The Hoogendoorn iSii (version 6) system consists of 4 sections: climate control, general control, irrigation-fertilization control and energy management. Figure 12 shows all the main and sub-menu headings accessible to Hoogendoorn automation users.

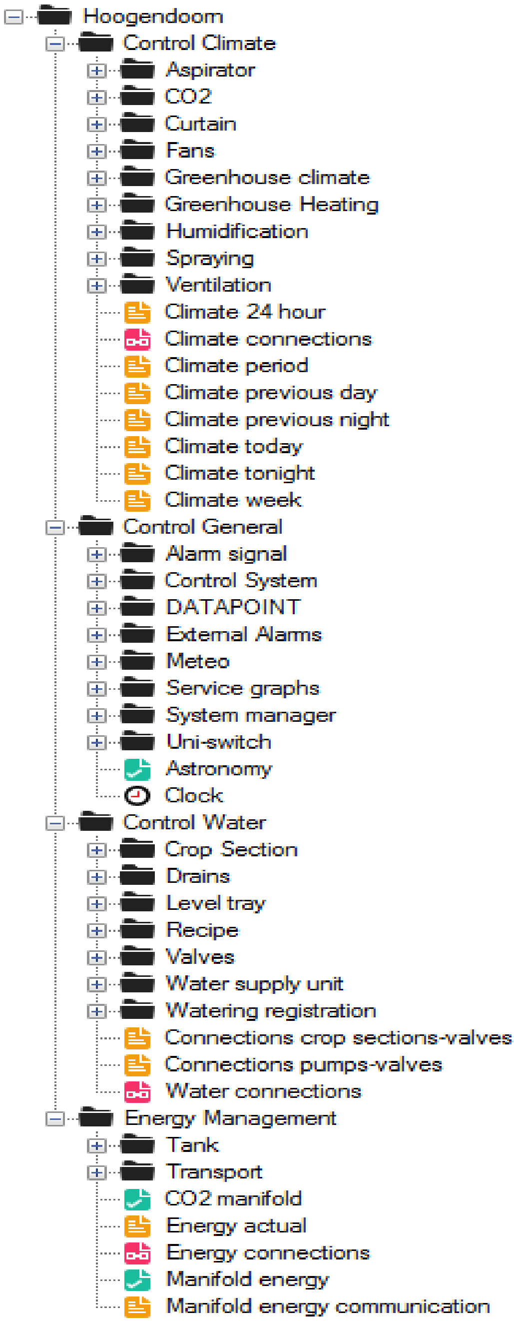

Figure 12. Hoogendoorn iSii menu

3.2.5.1.5 Hoogendoorn Graphical Analysis

The Hoogendoorn automation provides graphical access to real-time growth data on greenhouse climate, energy consumption and production.

This data is retrieved from the automation process computer and can be compared for multiple periods and locations. Users can create their own dashboards to provide an overview and control processes. Figure 13 shows a graph created by a hoogendoorn user for irrigation.

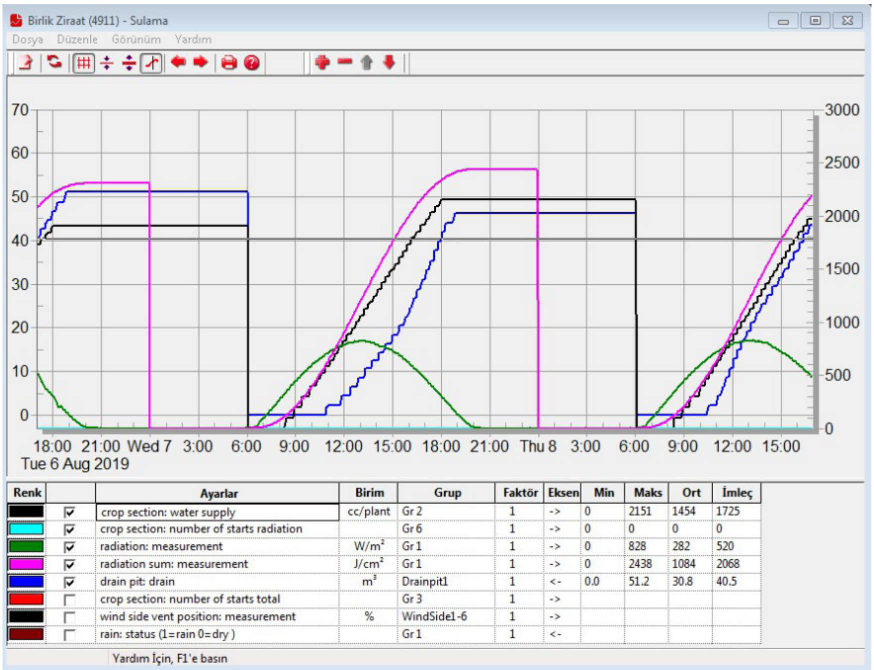

Figure 13. Hoogendoorn irrigation graph

In this study, examples of components used in automation applications in soilless agriculture are given. Apart from these components, many different components are also used in automation applications. In soilless agriculture applications, irrigation valves, fertilizer dosing units, ventilation fans, lighting schemes are usually controlled by a control unit. These components are the output components in soilless agriculture applications. Input information can be obtained from the growing environment with the types of relative humidity, temperature, soil moisture, radiation sensors selected for the purpose. This information is processed by the software in the control unit. Control units and software can be developed by researchers for different purposes, as well as solutions produced by commercial companies. The growers should choose the hardware and software components suitable for their production system.

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gece kitaplığı

BÖLÜM 3

COMPONENTS OF PRECISION AGRICULTURE

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As the worldwide populace keeps on growing, the requirement for supportable and proficient agrarian practices turns out to be progressively indispensable. In this specific situation, accuracy horticulture has arisen as a progressive way to deal with cultivating that use trend setting innovations to enhance efficiency while limiting ecological effect. By coordinating information investigation, remote detecting, and computerization, accuracy horticulture is changing the manner in which ranchers deal with their harvests, prompting further developed yields, asset preservation, and financial advantages. In this article, we will investigate the idea of accuracy agribusiness, its key parts, and the momentous benefits it offers to current cultivating.

Accuracy horticulture, otherwise called satellite cultivating or site-explicit yield the executives, is a cultivating procedure that utilizes state of the art innovations to screen, examine, and oversee rural practices at an exceptionally limited and exact level. It rotates around the idea that each square meter of a homestead can have extraordinary necessities, which can be tended to through redid mediations. By gathering information from different sources and using constant observing frameworks, accuracy agribusiness empowers ranchers to go with informed choices and execute designated techniques to enhance crop development and asset usage.

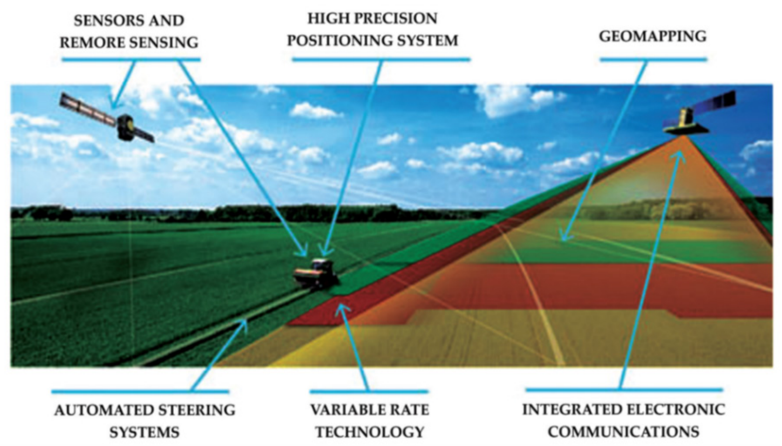

Figure 1. *Various technologies used in precision agriculture (CEMA, 2024)*

Components of Precision Agriculture

a. Remote Detecting: Remote detecting advances, like satellite symbolism, robots, and sensors, assume a urgent part in accuracy farming. These instruments furnish ranchers with important data about soil wellbeing, crop development, dampness levels, and vermin invasions. By dissecting this information, ranchers can recognize trouble spots, survey crop conditions, and make proper moves, bringing about exact intercessions and further developed asset portion.

Remote detecting is a critical part of accuracy horticulture that assumes a pivotal part in social event significant data about crop wellbeing, soil conditions, and other significant variables for compelling homestead the executives. It includes the utilization of different innovations to gather information from a good ways, normally through satellite symbolism, robots, and sensors. This information is then broke down to give ranchers important experiences and guide dynamic cycles (Colomina and Molina, 2014; Sishodia et al., 2020; Xue and Su, 2017).

Here are the vital parts of remote detecting in accuracy farming:

Satellite Symbolism: Satellites outfitted with specific sensors catch pictures of rural fields from space. These pictures give a higher perspective of the whole ranch, permitting ranchers to screen huge regions and distinguish examples and varieties in crop wellbeing. Satellite imagery offers insights into crop vigor, vegetation indices like the Normalized Difference Vegetation Index (NDVI), soil moisture, and other pertinent parameters. By analyzing these images, farmers can identify early signs of stress, nutrient deficiencies, pest infestations, and diseases, allowing them to take timely action (Ahmad & Mahdi, 2018).

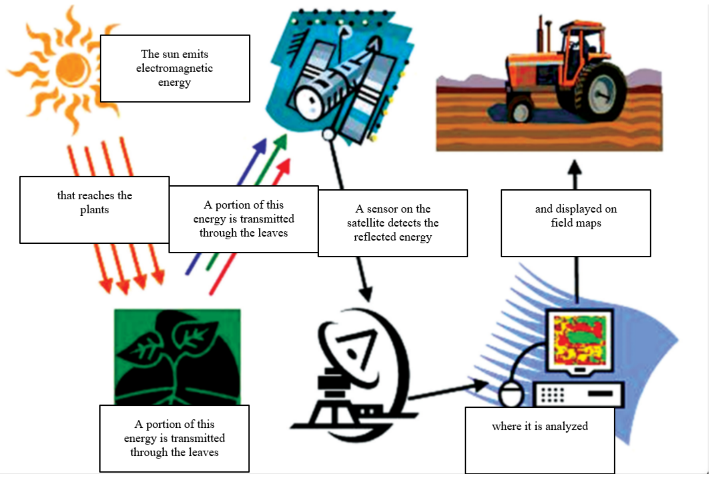

Figure 2. *The process of satellite remote sensing as applied to horticultural monitoring involves several steps (Zachariah, 2019).*

Drones, or unmanned aerial vehicles (UAVs), have gained popularity in precision agriculture. They offer greater flexibility and can provide real-time or near-real-time information about crop health, growth stages, irrigation patterns, and pest outbreaks. Drones allow farmers to monitor smaller sections of their fields with high precision, enabling targeted interventions and reducing the need for manual inspections (Huang et al., 2013; Kale et al., 2015; Marinello et al., 2016)

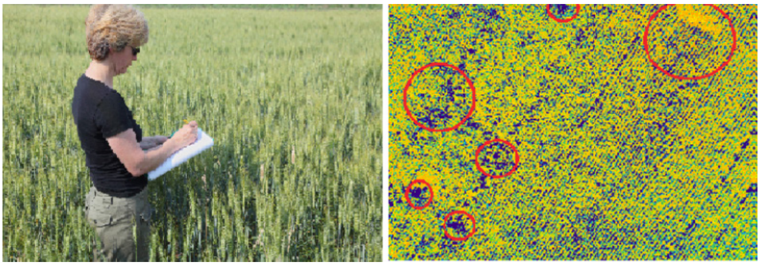

Figure 3. *Crop Scouting—Manual (left) and Drones (right) (Zachariah, 2019).*

Sensors: Various types of sensors, such as multispectral and hyperspectral sensors, are used in precision agriculture to collect data on specific parameters. Multispectral sensors capture data in multiple bands of the electromagnetic spectrum, providing insights into crop health, water stress, nutrient content, and disease presence. Hyperspectral sensors offer even higher spectral resolution, allowing for more detailed analysis of crops, including identification of specific diseases or nutrient deficiencies. Sensors can be mounted on drones or ground-based equipment, providing farmers with localized and accurate data for precise decision-making (Shafi et al., 2019; Xue & Su, 2017).

Figure 4. *Parts of a consolidate mounted yield-observing framework. Clockwise from left, Movement sensor, yield screen, worldwide situating framework, yield-screen show, and information recording gadget. (Morgan, & Ess, 1997).*

Data Analysis: Data collected through remote sensing techniques is processed and analyzed using advanced algorithms and techniques. This analysis can involve image classification, calculation of vegetation indices, and pattern recognition to derive meaningful information from the captured images and sensor data. Machine learning algorithms can detect anomalies, predict crop yields, identify disease outbreaks, and optimize resource allocation. Insights from data analysis help farmers make informed decisions about irrigation scheduling, fertilizer application, pest management, and other critical aspects of farm management.

Integrating remote sensing technology in precision agriculture allows farmers to understand their fields' spatial variability comprehensively and make informed decisions at a localized level. It enables them to identify and respond to crop stressors, optimize resource usage, and enhance overall farm productivity while minimizing environmental impacts. By leveraging remote sensing techniques, precision agriculture maximizes the efficiency and effectiveness of farming practices, leading to sustainable and profitable agricultural operations.

b. Data Analytics: Precision agriculture heavily relies on data analytics to process large volumes of information collected from various sources. Advanced algorithms and machine learning techniques provide insights into crop performance, predict disease outbreaks, optimize irrigation schedules, and create customized fertilization plans. By harnessing the power of data, farmers can optimize their farming practices and make data-driven decisions for improved efficiency and productivity (Xue & Su, 2017).

Data analytics plays a crucial role in precision agriculture by processing and analyzing large volumes of data collected from various sources, such as remote sensing, weather stations, and on-farm sensors. Through advanced algorithms and techniques, data analytics provides valuable insights into crop health, growth patterns, environmental conditions, and other factors influencing agricultural productivity.

Data Collection and Integration: Data collection in precision agriculture involves gathering information from multiple sources, including satellite imagery, drones, sensors, weather stations, and on-farm equipment. This data includes vegetation indices, soil moisture levels, weather patterns, crop yields, and more. Data integration merges these diverse datasets into a unified format for analysis and interpretation. By combining data from various sources, farmers can gain a comprehensive understanding of their fields and make more informed decisions.Data Preprocessing: Before analysis, raw data collected from different sources often requires preprocessing. This step involves cleaning, filtering, and organizing the data to ensure its quality and consistency. It may include removing outliers, handling missing values, and standardizing data formats. Preprocessing optimizes the data for further analysis, reducing errors and improving the accuracy of results.

Descriptive Analytics: Descriptive analytics focuses on summarizing and visualizing the collected data to gain insights into historical patterns and trends. Statistical methods, visualization tools, and techniques such as data aggregation, averaging, and clustering are employed to understand the distribution of variables, identify spatial patterns, and explore correlations between different factors. Descriptive analytics helps farmers gain a comprehensive overview of their fields, identify areas of concern, and monitor changes over time.

Predictive Analytics: Predictive analytics uses historical data to develop models and algorithms that can forecast future outcomes and trends. Machine learning algorithms are commonly applied in precision agriculture. These models can predict crop yields, disease outbreaks, irrigation requirements, and other important parameters. By leveraging predictive analytics, farmers can anticipate potential issues, optimize resource allocation, and make informed decisions to mitigate risks and maximize productivity.

Prescriptive Analytics: Prescriptive analytics takes predictive analysis a step further by providing actionable recommendations and strategies based on the analyzed data. By considering various scenarios and constraints, prescriptive analytics algorithms suggest optimal interventions for resource allocation, such as determining the right amount of water, fertilizer, or pesticide for specific areas of a field. Prescriptive analytics helps farmers optimize their operations, enhance resource efficiency, and improve overall farm performance.

Real-Time Monitoring: Data analytics in precision agriculture can also involve real-time monitoring and decision-making. By integrating data streams from on-farm sensors, and other sources, farmers can receive up-to-date information about crop conditions, soil moisture levels, and pest outbreaks. This enables timely interventions and adjustments to farming practices, enhancing responsiveness and maximizing crop health and productivity.

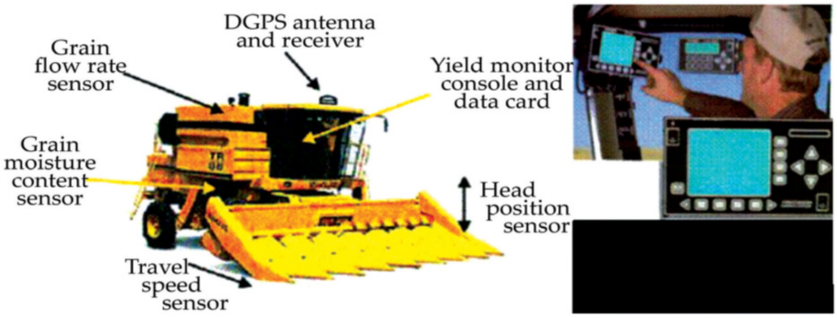

Figure 5. *Consolidate parts for yield checking and planning, show console in inset (Moran et al., 1997)*

It empowers them to detect and address issues promptly, predict outcomes, and implement precise strategies that lead to sustainable and efficient agricultural practices.

c. Variable Rate Technology (VRT): Variable Rate Technology allows farmers to apply inputs such as water, fertilizers, and pesticides at variable rates based on the specific needs of different areas within a field. By precisely matching inputs to the requirements of individual plants or sections, VRT reduces waste, optimizes resource usage, and minimizes the environmental impact of farming activities. This targeted approach leads to improved crop quality, reduced input costs, and enhanced sustainability (Ahmad, & Mahdi, 2018).

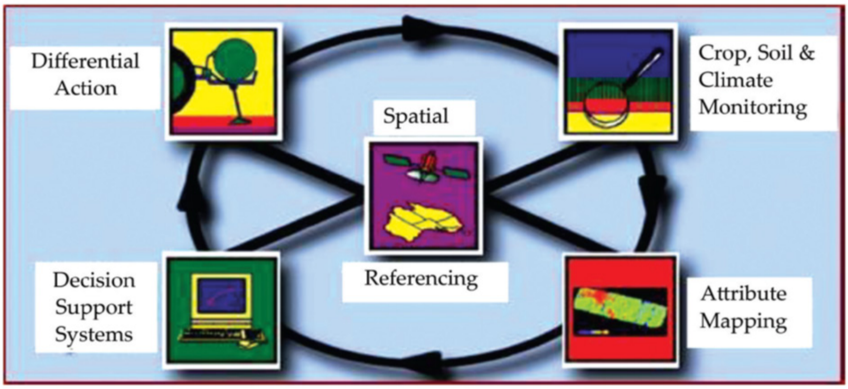

Figure 6. *Parts of site-explicit land the executives (Adhikari et al., 2009)*

Variable Rate Technology (VRT) is a key component of precision agriculture that enables farmers to apply inputs such as water, fertilizers, and pesticides at variable rates based on the specific needs of different areas within a field. Rather than using a uniform application rate across the entire field, VRT takes into account variability in soil conditions, crop requirements, and other factors to optimize resource usage. Here's a closer look at Variable Rate Technology in precision agriculture (Alameen, Al-Gaadi, Tola, 2019):

Data Analysis and Mapping: VRT begins with the collection of data from various sources such as soil maps, remote sensing, and on-farm sensors. This data is analyzed to identify spatial variations in soil fertility, moisture levels, organic matter content, topography, and other relevant factors. By integrating this information, farmers can create detailed field maps that highlight areas with differing needs and characteristics.

Prescription Map Development: Based on the field maps and data analysis, farmers generate prescription maps that specify the recommended application rates for different inputs across the field. These maps are tailored to address specific requirements, such as fertilizer needs, irrigation levels, or pest control, for each area within the field. Prescription maps can be created using specialized software or farm management systems that take into account agronomic knowledge, historical data, and crop-specific requirements.

Application Equipment and Controllers: VRT requires compatible application equipment and controllers that can adjust input rates on the go. For instance, for variable rate fertilization, farmers may use equipment that allows for the adjustment of fertilizer application rates on a per-section or per-row basis. The controllers receive input from the prescription maps and adjust the application rates accordingly as the equipment moves across the field. This allows for precise and targeted input application based on the specific needs of each area.

Benefits of VRT

Resource Optimization: VRT optimizes resource usage by applying inputs precisely where they are needed, avoiding wastage in areas that require less. By matching inputs to the specific needs of different areas, farmers can optimize nutrient application, irrigation, and pest control. This approach not only reduces input costs but also minimizes the environmental impact associated with excessive application of inputs.

Improved Crop Performance: VRT allows farmers to tailor input applications to meet the specific requirements of different areas within a field. By providing optimal levels of water, fertilizers, and pesticides, VRT promotes better crop health, growth, and yield. This targeted approach helps maximize the productivity and quality of crops.

Uniformity and Consistency: VRT helps achieve uniformity in input application across a field. By addressing spatial variability, farmers can avoid over- or under-application of inputs, resulting in more consistent crop performance. This consistency contributes to improved quality and marketability of the harvested produce.

Environmental Sustainability: VRT contributes to environmental sustainability by reducing the potential for nutrient leaching, soil erosion, and water contamination. By applying inputs at variable rates based on soil and crop needs, farmers can minimize the risk of environmental damage and promote sustainable farming practices.

Cost Savings: VRT offers potential cost savings by optimizing resource usage and reducing input waste. By applying inputs more efficiently, farmers can reduce the overall amount of inputs required, leading to cost reductions. Moreover, by preventing excessive application of inputs in low-need areas, farmers can avoid unnecessary expenses.

Variable Rate Technology (VRT) is a powerful tool in precision agriculture that allows farmers to tailor input applications to the specific needs of different areas within a field. By optimizing resource usage, improving crop performance, promoting environmental sustainability, and offering cost savings, VRT significantly enhances overall farm efficiency and productivity.

d. Automation and Robotics: Automation and robotics are increasingly being integrated into precision agriculture systems. Autonomous vehicles, robots, and drones can perform a range of tasks, including planting, spraying, monitoring, and harvesting, with high precision and efficiency. These technologies minimize human labor, reduce operational costs, and enable farmers to focus on higher-level decision-making. Additionally, automation facilitates round-the-clock monitoring and management of crops, further enhancing overall farm productivity.

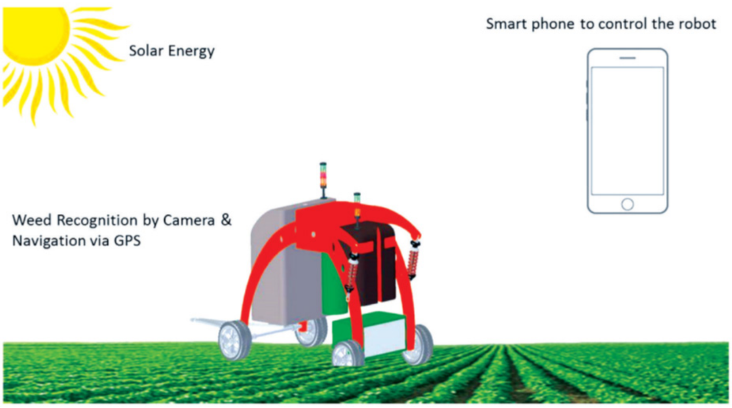

Figure 7. *Working principle of weed detection and spraying robot (Singh et al., 2022).*

Automation and robotics are playing an increasingly important role in precision agriculture, revolutionizing the way farming operations are carried out. These technologies bring efficiency, accuracy, and scalability to various tasks, ranging from planting and spraying to monitoring and harvesting. Here's an explanation of automation and robotics in precision agriculture:

Planting and Seeding: Automated planting and seeding systems utilize robotics and precision guidance technology to precisely place seeds in the soil. These systems can maintain consistent spacing between seeds, optimize seed depth, and ensure uniform distribution, resulting in improved crop emergence and stand establishment. Automated planting reduces labor requirements, enhances planting accuracy, and enables farmers to cover large areas efficiently.

Spraying and Application: Automated spraying systems, such as robotic sprayers, enable precise and targeted application of fertilizers, herbicides, and pesticides. Equipped with sensors, GPS technology, and advanced algorithms, these systems can detect and selectively treat areas affected by pests or diseases. By precisely applying inputs only where needed, automated spraying reduces chemical usage, minimizes environmental impact, and improves the effectiveness of pest and disease control.

Monitoring and Sensing: Robotics and automation play a crucial role in monitoring crop health, collecting data, and sensing environmental conditions. Drones equipped with cameras and sensors can capture high-resolution images and gather data on crop health, growth patterns, and soil conditions. Autonomous ground-based robots can navigate fields and collect real-time data on plant height, nutrient levels, and soil moisture. These technologies enable farmers to continuously monitor their crops and make informed decisions based on timely and accurate information.

Harvesting: Automation and robotics are being increasingly applied to harvesting operations in precision agriculture. Autonomous harvesters can identify ripe crops, perform selective harvesting, and accurately determine the optimal time for harvest. These technologies increase harvesting efficiency, reduce labor requirements, and minimize crop damage during harvesting, leading to improved quality and yield.

Data Collection and Integration: Automation and robotics enable seamless data collection and integration into precision agriculture systems. Robots and sensors can be deployed across fields to collect data on soil conditions, plant health, and environmental parameters. This data is then integrated with other sources, such as weather data, satellite imagery, and historical records, to provide a comprehensive understanding of the field's conditions. Automated data collection ensures the availability of accurate and up-to-date information for analysis and decision-making.

Benefits of Automation and Robotics (Chen et al., 2016; Defourny et al., 2019):

a. Labor Efficiency: Automation and robotics reduce the labor-intensive nature of farming operations. With autonomous systems taking over tasks such as planting, spraying, monitoring, and harvesting, farmers can allocate their labor resources to more strategic and value-added activities.

b. Precision and Accuracy: Automated systems provide a high level of precision and accuracy in various farming operations. From planting seeds at the optimal depth to applying inputs with pinpoint accuracy, automation ensures consistent and targeted actions, resulting in improved crop performance and resource utilization.

c. Scalability: Automation and robotics enable scalability in farming operations. With the ability to cover large areas efficiently and consistently, these technologies facilitate the management of expansive farms and support the adoption of precision agriculture on a larger scale.

d. Time and Cost Savings: By automating repetitive and time-consuming tasks, farmers can save time and reduce operational costs. Automated systems work efficiently and consistently, minimizing errors and waste, and enabling farmers to focus on decision-making and higher-level tasks.

e. Sustainability: Automation and robotics contribute to sustainability in agriculture. By optimizing resource usage, reducing chemical inputs, and minimizing crop damage, these technologies promote environmental stewardship and support sustainable farming practices (Berthet et al., 2019).

Automation and robotics are revolutionizing the agricultural industry, introducing precision, efficiency, and sustainability to farming operations. By harnessing these technologies, farmers can boost productivity, optimize resource utilization, and enhance overall farm management within the framework of precision agriculture.

Benefits of Precision Agriculture

Precision agriculture offers numerous benefits to farmers and the agricultural industry as a whole. Here are some expanded benefits of precision agriculture:

Enhanced Crop Yields: Precision agriculture techniques optimize crop growth conditions by addressing the specific needs of plants at a localized level. Farmers can utilize data on soil conditions, weather patterns, and crop health to make informed decisions about irrigation, fertilization, and pest control. This precision in managing inputs leads to healthier crops, minimized losses, and ultimately, improved yields.

Resource Efficiency: Precision agriculture optimizes the use of resources such as water, fertilizers, and pesticides. By applying inputs in a targeted manner based on field variability, farmers can reduce waste and ensure efficient resource utilization. This efficient resource management not only cuts costs but also mitigates the environmental impact associated with excessive input use, promoting sustainability in agriculture.

Cost Savings: Precision agriculture helps farmers make data-driven decisions regarding resource allocation. By using real-time data, predictive models, and prescription maps, farmers can optimize the use of inputs, reduce unnecessary expenses, and maximize the return on investment. By avoiding over-application of inputs and targeting interventions where they are needed, precision agriculture can result in significant cost savings for farmers.

Environmental Sustainability: With its focus on efficient resource management, precision agriculture helps mitigate the negative environmental impacts associated with conventional farming practices. By minimizing the use of water, fertilizers, and pesticides through precise application, precision agriculture reduces water pollution, soil erosion, and greenhouse gas emissions. This sustainable approach ensures that agriculture can coexist harmoniously with the environment (Berthet et al., 2019).

Data-Driven Decision Making: Precision agriculture relies on data analytics, remote sensing, and real-time monitoring systems to provide farmers with valuable insights. By analyzing data on crop health, soil conditions, weather patterns, and more, farmers can make informed decisions to optimize farming practices. Data-driven decision making leads to increased efficiency, reduced risk, and improved outcomes in crop production.

Early Detection of Issues: Precision agriculture enables early detection of issues such as nutrient deficiencies, pest infestations, and diseases. By utilizing remote sensing technologies and data analytics, farmers can identify problem areas in their fields and take timely action to prevent further damage. Early detection allows for proactive intervention, minimizing crop losses and preserving overall crop health.

Customization and Personalization: Precision agriculture recognizes that each area of a field may have unique requirements. By creating prescription maps and implementing variable rate technology, farmers can customize interventions based on the specific needs of different sections within a field. This customization leads to tailored strategies for each area, optimizing inputs and maximizing crop performance.

Improved Farm Management: Precision agriculture offers advanced tools and technologies that enhance farm management practices. From automated planting and spraying systems to real-time monitoring and data analytics, precision agriculture empowers farmers with actionable insights and efficient tools for decision-making. This leads to improved farm planning, increased operational efficiency, and better overall management of agricultural resources.

Precision agriculture is revolutionizing farmers' approach to crop production. Through the utilization of advanced technologies and data-driven techniques, precision agriculture presents a multitude of benefits, including enhanced crop yields, resource efficiency, cost savings, environmental sustainability, and improved farm management. These advantages play a crucial role in ensuring the long-term viability and sustainability of agriculture, addressing the challenges associated with feeding a growing global population.

A few examples of precision agriculture practices along with references for further reading:

Variable Rate Fertilization: Variable rate fertilization involves applying fertilizers at varying rates across a field based on soil nutrient levels and crop requirements. Soil sampling and analysis are conducted to determine nutrient deficiencies and create prescription maps for precise fertilizer application. This practice optimizes fertilizer usage, reduces costs, and minimizes environmental impact.

Precision Irrigation: Precision irrigation optimizes water application to crops by utilizing soil moisture sensors, weather data, and crop water requirement models to determine irrigation needs. This targeted approach enables farmers to deliver the precise amount of water to various areas of the field, thus maximizing water efficiency and minimizing water stress (Abioye et al., 2022; Adeyemi et al., 2017).

Automated Crop Monitoring: Automated crop monitoring utilizes remote sensing technologies such as drones and satellite imagery to monitor crop health, growth, and stress factors. By analyzing multispectral or hyperspectral images, farmers can identify areas of concern, such as pest infestations or nutrient deficiencies, and take targeted actions. This practice enables early detection of crop issues and improves decision-making for timely interventions.

Integrated Pest Management (IPM): Integrated Pest Management combines various precision agriculture practices to effectively manage pests while minimizing the use of chemical pesticides. It involves the integration of pest monitoring systems, weather data, and predictive models to determine pest risks and implement targeted interventions, such as precision spraying or biological control methods. IPM practices reduce chemical inputs and promote sustainable pest management (Zhang et al., 2022; Falkenberg et al., 2022).

Robotic Harvesting: Robotic harvesting involves the use of autonomous robots equipped with computer vision and robotic arms to harvest crops. These robots can identify ripe fruits or vegetables, navigate fields, and perform precise harvesting actions. Robotic harvesting reduces labor requirements, improves harvesting efficiency, and minimizes crop damage during the harvesting process (Li et al., 2023; Wang et al., 2023).

These examples highlight the diverse range of precision agriculture practices being implemented to optimize resource usage, enhance crop management, and improve overall farming efficiency. The provided references delve into further details and research related to each practice.

Precision agriculture is reshaping the agricultural landscape by harnessing advanced technologies to boost productivity, conserve resources, and foster sustainability. Through the integration of data analytics, remote sensing, and automation, farmers can make informed decisions and deploy targeted strategies for effective crop management. With its capacity to augment yields, preserve resources, cut costs, and mitigate environmental footprints, precision agriculture offers significant potential in meeting global food demands while securing a sustainable future.

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