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Hydroponics: shaping the future of sustainable crop production

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Abstract

Hydroponics and smart technology are being used together in farming. This is a new idea that shows a lot of promise. This method of farming is good for the environment. It helps to grow crops in a way that is effective. The thing about this technology is that it does not need soil and it uses water because it gives nutrients straight to the roots of the plants. The Internet of Things and sensors and automation are all part of what's called "smart farming". This type of farming lets us watch the conditions of the soil and the levels of nutrients and the health of the plants all the time. We can use this information to manage and optimize the farming process. Hydroponics and smart technology help to grow crops and they help the crops to grow faster. They also help to keep the conditions right for the crops all year round no matter what the weather is like. Using Hydroponics and smart technology in farming is also good because it means we do not need to use many chemicals. It is a way of farming that's safe for the environment and it helps to cut down on waste. This new way of farming could make a difference in the way we grow food. It could help us to grow food in our regions and it could help to keep us safe from not having enough food. This review is about what's happening now with Hydroponics and smart farming. It talks about the things that are happening in smart farming like Domotics and Data Acquisition and Remote Cultivation and automated AI systems. The review also talks about the types of smart farming and the good things about Hydroponics and smart technology. It says what we need to do to make this type of farming work well. It also talks about what we might see in the future and how we can make Hydroponics and smart farming even better. This will help us to keep making progress in this area and to make Hydroponics and smart farming a big part of the way we grow food. Hydroponics and smart technology are really important for the future of farming. Hydroponics and smart technology can help us to grow food in a way that's good for the environment and that helps to keep us safe. We need to keep working on Hydroponics and smart technology so that we can make it even better. This will help us to have a future and to be able to grow food in a way that is good for everyone. The use of Hydroponics and smart technology, in farming is a thing and it will help us to have a better life. Hydroponics and smart technology are the future of farming. We need to keep working on them.

Keywords: Hydroponics, smart farming, Internet of Things (IoT), precision agriculture, soilless cultivation

1. Introduction

Hydroponics is a way of growing plants in water that has lots of nutrients in it of using soil. The word "hydroponics" comes from the words "hydro" which means water and "ponos" which means work. People use things like peat moss and charcoal to help support the roots of the plants in hydroponic systems. The system is designed to give plants the amount of water, nutrients and oxygen to grow well. Hydroponics is used by people at home and by companies to grow all sorts of plants like vegetables and fruits and flowers. People have been trying to grow plants without soil for thousands of years. The modern way of doing hydroponics was developed in the middle of the 20th century. This was because people wanted to find a way to grow food in places where they did not have a lot of space or good soil. A time ago someone made the Hanging Gardens and they probably used hydroponics to grow the plants. A man named Jan van Helmont did some experiments to show that plants can grow without soil. He did this a time ago in the 17th century. On some other scientists named De Saussure and Boussingault found out that plants need things like carbon and oxygen to grow. Then some other scientists named Sachs and Knop did some experiments and they found out that plants need other things like phosphorus and potassium to grow too. A man named William Frederick Gericke thought that

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growing plants without soil was an idea. He did a lot of experiments to show that plants can grow well in water if they have the nutrients. He used plants like lettuce and tomatoes to do his experiments. Because of the work that Gericke did we now have an understanding of how to grow plants without soil. Today hydroponics is used in lots of places to grow all sorts of plants. It is a way to grow plants because it uses less water and can help us grow more food. Hydroponics is good for the earth because it helps us grow food in a way that's sustainable. It also helps us use water, which is important because water is a precious resource. People are becoming more interested in hydroponics because it can help us solve some of the problems that we have with growing food. For example it can help us grow food in places where the soil is not good. It can also help us use water, which is important for the earth. So hydroponics is a way of growing plants in water that has lots of nutrients in it. It is a way to grow plants because it uses less water and can help us grow more food. Hydroponics is used by people, at home and by companies to grow all sorts of plants. It is a way to help us have more food and to take care of the earth.

2. Methods

The goal of this review is to talk about what we found out about how different materials affect the growth of hydroponic lettuce. We want to look at how things like coconut coir, rockwool, perlite, vermiculite and peat moss impact the lettuce. We will see how these materials affect things like how the soil holds water how the roots grow and how the plants get the food they need. This review is also about understanding how these materials affect the amount of lettuce we can grow. We also want to give people who grow hydroponic lettuce some information to help them choose the best material to use. We will look at how the materials affect the cost the environment and the way the plants grow. This review will also show what we do not know yet about using these materials to grow hydroponic lettuce. This will help us figure out what we need to study especially when it comes to finding the best material to use to get the most lettuce in a hydroponic system. Hydroponic lettuce growth is what we are focusing on. We want to know which material is the best, for hydroponic lettuce production.

3. Hydroponics System

Dr. W. F. Gericke came up with the term Hydroponics in 1936. He wanted to grow plants in water without using soil. The term Hydroponics basically means working water. It comes from two words: hydro which means water and ponos which means labor. If we look back in time people were growing plants in water a time ago. For example there were the hanging gardens of Babylon the Aztecs in Mexico and China and the floating gardens. Dr. W. F. Gericke was the person to use Hydroponics in the United States of America on a big scale. He started using Hydroponics in 1930. Introduced the idea of hydroponic units. The United States used Hydroponics to grow vegetables during the Second World War. Dr. W. F. Gericke and Hydroponics helped the US to grow food in the Pacific. There are ways to use Hydroponics. Here are five common ways:

- the nutrient film technique
- the ebb and flow technique
- the aeroponics technique
- the wick system
- the water culture method. These are all types of Hydroponics systems that people use to grow plants, in water

3.1 The Wick System

The wick system is a way to help plants grow inside. It is a way to give water to plants. The wick system uses a material like nylon to get water from a container. This material helps get water to the roots of the plant. The wick system is good for gardens at home or in an office. It is great for plants that have flowers. The wick system is not good for plants or plants that need a lot of water. It does not give plants water. This is a problem for plants that need a lot of water to grow. The wick system is different from ways to water plants. It is not, like a system that uses a water pump. The wick system is simple. That is why people like to use it for small gardens.

3.2 The Drip System

Drip systems come in two types.

One is the recovery system. It uses recycled water or nutrient solution. The recovery system. Reuses the water/nutrient solution. It sends it back to its storage tank. This method has some issues. The solutions pH level can change. Algae or mold can grow in the tank or tubes.

Experts think the recovery system works better. It is better than the -recovery model. The non-recovery drip system needs checks. You have to check the water or nutrient solution. This ensures it reaches the plant roots properly. Experts like Santamaria *et al.* (2003) Have studied this. They found that checks are necessary. Schröder and Lieth (2002) also did research, on drip systems. They looked at how recovery systems work.

3.3 The ebb and Flow System

Ebb and Flow Hydroponic Systems are a way to grow plants without using soil. They work by flooding the medium that the plant is growing in with water that has nutrients in it. Then letting it drain back into a container. This helps the plants get the nutrients they need and makes sure their roots get oxygen. For a time people used timers to control when the medium got flooded and drained but this often meant that some of the nutrients got wasted. To make this better some people thought of using something called logic control. This means that the system can adjust when the pump is on or off based on what's happening in the environment like how wet or dry the medium is and what the temperature is. You can make a system like this using a things, including a sensor to check the moisture a sensor to check the temperature an Arduino UNO microcontroller and a pump that runs on direct current. Using logic control can help get the nutrients to the plants in a better way and cut down on waste which can make the plants grow a lot better and make the whole system work more efficiently like what Daud and his team found out in their research in 2018. Ebb and Flow Hydroponic Systems that use logic control are really good, at helping plants grow. Ebb and Flow Hydroponic Systems can be very effective when they use logic control to deliver nutrients (Daud *et al.*, 2018) ^[2].

3.4 The deep water culture

Deep water culture is a way of growing plants where the roots are always in a special liquid that has lots of good stuff for the plants. To help the plants grow well we need to keep an eye on how deep this liquid is. We can use a tool called an HC-SR04 ultrasonic sensor to always check the level of the liquid. If the liquid gets too low a little pump that uses 12V DC power will turn on. Fill up the tank again so the roots get the food they need. We can use a kind of math called linear regression to figure out how long the pump should be on. This way we can

make sure the liquid is always at the level and the system is very good at doing this getting it right almost all the time. We can even use an Android phone to control the thing, which makes it easy for people to make changes and give the plants what they need. Using machines to do things and being able to control them from far away are great ways to keep everything just right for the plants in a deep water culture system as seen in the work (Nursyahid *et al.*, 2021).

3.5 The nutrient film technique (NFT) system

In NFT systems, nutrient solution flows right over the roots, so plants soak up both nutrients from the water and oxygen from the air. This setup makes nutrients available all the time, so plants don't run low. Plus, NFT uses a lot less water than growing in soil, since only part of the roots sit in water while the rest stay exposed to air — giving them plenty of oxygen. That extra oxygen means plants grow faster and healthier. With no soil involved, you don't really have to worry about pests or diseases hiding in the dirt. NFT is popular for speeding up growth and boosting yields. Because it's not bulky, it works great for small-scale setups like urban gardens or greenhouses.

3.6 Substrates in Hydroponics

Hydroponic substrates do a couple of big jobs: they hold up your plants and help roots soak up nutrients. People use different kinds, and each has its ups and downs. Rockwool is everywhere, but honestly, it's not great for the planet—it's not biodegradable, and handling it can kick up some dust. Expanded clay balls are popular too, mostly because they let air and water move through easily. Perlite is another lightweight option and really helps with aeration, but don't expect it to hold much water. Coconut chips are a smart pick—they're organic, renewable, and keep moisture well. That makes them a sustainable choice for many growers. Phenolic foam is light and good at holding water, but since it's basically plastic, it ends up adding to pollution. These days, new eco-friendly options are popping up, like keratin-based substrates from hair or feathers and cellulose-based ones from wood pulp. They're biodegradable, retain water well, and let growers control how nutrients reach the plants. In short, modern substrates are helping hydroponics get greener and giving roots what they need (Zhao *et al.*, 2022) ^[14].

3.7 Advantages of Hydroponic Systems

Hydroponics lets you grow plants fast without needing much water or land. Plus, the harvests are healthy, renewable, and strong. Farmers get high-quality feed for their animals, which raises both their living standards and their yields. The system cuts out pesticides and keeps carbon emissions low. Sure, getting started costs a lot, but once it's up and running, you don't need many workers or much money to keep it going. Still, there are some drawbacks. You need technical know-how, seeds can be expensive, and fungal diseases or waterborne infections sometimes pop up. But honestly, once you get the hang of hydroponics, the benefits of reliable production really pay off (Ghorbel *et al.*, 2022) ^[15].

3.8 Disadvantages of Hydroponic system

Hydroponic systems don't come cheap. You need special gear and structures to set them up, so the initial investment can get pretty hefty. Plus, you need people who know what they're doing—understanding plant biology and knowing exactly how the system runs is essential. If something goes wrong with the tech, you can stress out or even kill your plants in a hurry. Nutrient management is a constant battle, too. You have to keep

the nutrient balance just right. Mess that up, and you run into trouble. There's also the risk of environmental pollution if you don't properly handle or dispose of the nutrient solutions. That pollution can seriously threaten local ecosystems. Hydroponics isn't a one-size-fits-all system. You can't grow every crop this way since some need unique conditions to truly thrive. Finally, hydroponics leans heavily on technology, which isn't practical in places without solid infrastructure or reliable access to the right equipment.

3.9 Economic and environmental considerations

Economic Viability: We looked at the project's financial outlook from a few different angles—like Net Present Value (NPV), Internal Rate of Return (IRR), Modified Internal Rate of Return (MIRR), Cost Benefit Analysis (C/B), Profitability Index (PI), Equivalent Annual Value (EAV), and Discounted Payback (DP). After weighing the numbers, even with risks and uncertainty in mind, we found that the hydroponics system works. It's not just feasible, it's a solid and sustainable option for small family farms. **Access to Credit:** Rural producers need easier access to credit, so they can invest in things like greenhouses and other essentials. The National Programme for Strengthening Family Agriculture (PRONAF) makes a big difference here. With its low-interest loans, farmers can actually build greenhouses and try out hydroponic farming. **Sustainability and Efficiency:** Hydroponics uses very little water and electricity compared to traditional farming. That's a huge perk. Even better, it gives small farmers a more stable, reliable supply—something they desperately need when market conditions are all over the place. **Innovative Practices:** For even more sustainability, the study recommends adding photovoltaic energy and collecting rainwater (Souza *et al.*, 2023) ^[10]. It's all about finding smarter ways for these systems to work long-term.

3.10 Challenges of hydroponic farming

Setting up a hydroponic system isn't cheap. You need pumps, artificial lighting, and equipment to keep nutrients circulating—none of that comes cheap, especially if you're just starting out or working with a small budget. Then there's the know-how. Hydroponics isn't something you just pick up overnight. You've got to understand how plants grow, what nutrients they need, and how to keep the whole system healthy. Sometimes, you have to take training courses just to run things properly. Pests are less of a headache compared to traditional farming, but diseases can spread fast in those tightly controlled environments. Managing that takes real attention. Clean water is also a big deal. The whole system relies on having good-quality water—if the water's off, your plants suffer. You have to constantly check the pH and nutrient levels to keep everything balanced. On top of all that, hydroponics leans heavily on technology—lots of monitoring, automation, and controls. If there's a power outage or one piece of equipment fails, crops are at risk fast. And, let's be honest, selling what you grow isn't always straightforward. Not everyone knows or trusts hydroponically grown produce, so sometimes it's tough to get the prices or demand you want.

3.11 Future Prospects

The United Nations says we'll hit 9.6 billion people by 2050, and that means food demand will shoot up by 70%. Right now, farmers are already using about 80% of the planet's arable land. So, just using more traditional farming isn't going to cut it. That's where hydroponics comes in—it offers a better way to grow food without putting extra strain on land and water. Hydroponic systems recycle water, so they use much less of it

compared to soil-based farming. That's a big deal for places struggling with water shortages. Plus, traditional farming often ends up with uneven nutrient spread in the soil, which can mean overfertilization and pollution. Hydroponics solves this by letting you control how and when plants get their nutrients, so there's barely any waste and much less damage to the environment. Climate, pests, and disease can mess with soil farming, making harvests unpredictable. With hydroponics, you're in charge of the temperature, light, and humidity, which cuts out most of those problems and makes crop yields more reliable. By tackling these challenges with fewer resources, hydroponics can play a big role in feeding our fast-growing global population.

4. Conclusion

Hydroponic farming isn't just a trend—it's genuinely changing how we think about growing food. Instead of relying on soil, this method lets you grow plants directly in water mixed with nutrients. That alone already solves a big chunk of the headaches traditional farmers face. For one, it uses way less water, which is a game changer in cities or drought-prone areas where every drop counts. Plus, you get to control exactly what nutrients your plants get, which means healthier crops and faster growth, all packed into smaller spaces. Some of the most popular hydroponic systems—like the nutrient film technique, deep water culture, and ebb and flow—give people options depending on what they want to grow and how much time or tech they want to invest. These systems aren't just clever; they help deal with stubborn problems like bugs and diseases that usually lurk in the soil. So, you don't need to worry so much about pesticides or surprise infestations wiping out a whole crop.

Now, hydroponics isn't perfect. Setting up these systems can cost quite a bit, and you have to know what you're doing. There's always the risk something technical could break down. For small-scale farmers or folks who aren't tech-savvy, that can make the whole idea seem out of reach. Then there's the environmental question. Most hydroponic setups rely on synthetic substrates, and it's not totally clear what long-term impact those might have. Managing nutrients, too, takes real skill, and mistakes can impact the environment if runoff isn't handled correctly. But even with these challenges, hydroponics has a solid economic argument behind it, especially when it's paired with things like rainwater harvesting or solar panels. Sure, it takes capital to get started—that part's unavoidable. But over time, operational costs can balance out, especially if farmers have creative ways to finance the setup or if prices for produce stay strong.

With global food demand expected to jump by 70% by 2050, we can't afford to ignore new farming methods. Hydroponics offers a path forward that doesn't require clearing more land or straining already-scarce water supplies. As tech keeps moving forward, especially with more automated systems and environmentally friendly growing materials, hydroponics will likely become more accessible and sustainable. If costs come down and we get smarter about resource management, there's a real chance hydroponic farming could help feed more people—without wrecking the planet.

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