International Journal of Research in Agronomy 2024; 7(4): 73-78

E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(4): 73-78
Received: 14-01-2024
Accepted: 27-02-2024

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Utilising crop residues as hydroponic media for sustainable food production system

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i4b.528

Abstract
Hydroponic farming has garnered interest as a sustainable agriculture method because of its ability to produce higher yields and efficiently use resources. This abstract investigates the benefits associated with utilising agricultural waste in hydroponic systems. Hydroponic systems can optimise resource efficiency and lessen environmental effect compared to conventional soil-based farming by recycling materials like Stalks and leaves left over from harvests. By decreasing dependency on artificial fertilisers and protecting natural resources, this approach offers a sustainable substitute. The viability and advantages of using crop residues as a component of hydroponic medium in sustainable production systems are examined in this abstract. When handled appropriately and incorporated into hydroponic systems, crop residues which are usually regarded as waste can function as beneficial organic substrates. These crop residues improve the growing media general fertility and health by contributing vital nutrients, organic matter, and microbial diversity. Reducing the use of synthetic fertilisers reduces the carbon footprint associated with their manufacturing and transportation, as well as nutrient runoff. By repurposing agricultural by-products, using crop wastes may also reduce production costs and support the circular economy. Crop residue also minimise soil erosion and the requirement for traditional tillage, which in turn improves soil health and biodiversity when used in hydroponic media. Enhancing nutrient release from crop leftovers and creating specialised hydroponic systems that can efficiently use a variety of agricultural wastes would require more study. The incorporation of agricultural leftovers into hydroponic systems, however, is an important step in improving food production's sustainability and resistance to global issues like resource shortages and climate change. Crop residue-based hydroponics has the potential to completely transform agriculture and open the door to a more sustainable future with further research, innovation, and teamwork efforts.

Keywords: Crop residues, growing media, hydroponics, sustainable food production

Introduction
In developing nations like India, where population, production, and economic growth are all on the rise, the sustainable management of agricultural waste has emerged as a major concern. Because of their enormous volume and lack of management capabilities, crop residues are one type of agricultural waste that has presented unique issues. Agricultural waste, also known as crop residues, can be repurposed as a growth medium in hydroponic systems. Crop residues are organic materials left over from farming activities, such as stalks, leaves, and husks. By using crop residues in hydroponics, farmers can turn waste into a valuable resource while improving soil health and reducing air pollution. As the primary staples of India are wheat and rice, which typically generate the majority of crop residue, the extensive cultivation of these crops to feed the nation's growing population has undoubtedly resulted in the generation of massive amounts of crop residue that the nation is unable to handle. In India, 500 Mt of agricultural leftovers are produced annually on average. A significant 140 Mt excess remains each year, of which 92 Mt is burned, mostly in the northern provinces of Punjab, Haryana, and Uttar Pradesh, even if the bulk is utilised as feed, raw material for energy production, etc. [1] In many developing countries, especially in Asia, burning surplus crop residue is a common practice [2, 3]. This leads to low productivity and poor crop yield for many farmers. However, there's a solution that can help tackle these issues: hydroponics.

All activities related to crop cultivation, the production and processing of vegetables and fruits, and the production of dairy, poultry, aquaculture, and meat that is connected with intensive agricultural methods and fertiliser usage result in agricultural waste and by-products. In addition to making good use of the excess biomass, this will also reduce pollution and boost farmer income if it is utilised intelligently and properly to create value-added goods and usable materials. Agricultural waste can be used as growing media in hydroponics. It is a technique of growing plants without soil. Instead, plants are grown in nutrient-rich water solutions tailored to their specific needs. This method offers precise control over the growing environment, including nutrient levels and pH, which can result in faster growth and higher yields compared to traditional soil-based farming. Plants grown hydroponically have roots that dangle into an aerated nutrient solution that can either be flowing or static, and the culture systems are soilless and can have inert substrates or no aggregates at all. Two fundamental concepts may be differentiated between the liquid or solution culture approaches. A continuous-flow solution culture, such as the nutrient film technique (NFT) and the deep flow technique (DFT), or a circulating approach (closed system) can be regarded as the initial principle. Roots can be consistently supplied with nutrients using flow solution culture methods like the DFT. Although they are highly adapted to automated management, plants might quickly get dehydrated if the solution's flow is interrupted for any reason. The second hydroponic concept, also known as the static solution culture or non-circulating method (open systems), is further subdivided into three system techniques: the capillary action technique, the floating technique, and the root dipping technique. When it comes to water efficiency and fertiliser use, closed hydroponic systems have a major advantage over open systems [3]. One of the key components of hydroponics is the growth medium, which provides support to plant roots. There are various types of growth media used in hydroponics, such as perlite, vermiculite, coconut coir and coco-peat. The choice of medium depends on factors like the type of hydroponic system and the specific needs of the plants. The most crucial elements influencing how a substrate or growth medium interacts with the nutrient solution are porosity, availability of water, water holding capacity, buffering capacity, and capability for cation exchange (CEC). These parameters control the rate at which the nutrient solution flows through them, the frequency of irrigation or fertigation needed, and the nutrient availability for the plants. The degree of oxygenation in the root zone as well as the way roots spread out through the material are both determined by pore space, or porosity. Water availability refers to the growth media's ability to let plant roots reach water, whereas water holding capacity defines how much water the medium can hold. Low buffering g rowing media can store a lot of water and have excellent water availability, but they will require more frequent irrigation. On the other hand, those with a lower water availability could be able to retain some water longer, protecting plants from drying out. An indicator of the similar connection, but between the nutrients and the medium, is cation exchange capacity. Higher CEC nutrients will bind more of them, which will decrease their immediate availability to plants but may increase the time intervals between fertigation events. More control over nutrient delivery is possible with a low CEC, but dosing must occur more often [4]. Crop residues, can be repurposed as a growth medium in hydroponic systems. Crop residues are organic materials left over from farming activities, such as stalks, leaves, and husks. For example – Almond shells, Rice hull, Hazelnut husks, Cocopeat, Peat moss, grape marc and so on. These organic materials play a crucial role in promoting plant growth and optimizing yields in hydroponic systems. These materials can be added to the nutrient solution to enhance its nutritional composition. These materials are carefully processed to ensure they provide essential nutrients without introducing contaminants. Proper management of nutrients is essential for healthy plant growth in hydroponics. Farmers should follow recommended guidelines to ensure the right balance of nutrients for optimal plant health and productivity. By incorporating organic materials into their hydroponic systems, farmers can promote sustainable agriculture practices and reduce their reliance on harmful chemical fertilizer, can improving soil health and reducing air pollution.

Organic media used in hydroponics

A. Coconut coir: A natural fibre made from the coconut husk is called coconut coir. It is a sustainable and eco-friendly option because it is a by-product of the coconut industry. The processed coir fibres are put to use in a variety of ways, one major usage being used as a hydroponic growth medium. The key properties of coconut coir are that it provides a stable pH, aeration, and water retention balance. It is used in hydroponics in various ways – growing media, seed starting and container gardening. As in growing media, coconut coir is frequently utilised as the main ingredient or a component of a growth medium. In order to produce a well-balanced substrate, it can be used alone or combined with other elements like vermiculite or perlite. Plants being grown determine the mixing ratios to be used or mixing ratios rely on the specific demands of each plant. During hydroponic seed germination, coconut coir is the perfect medium. Its water-retention qualities guarantee steady hydration for the early growth of seedlings, while its fine texture creates an ideal atmosphere for seed germination. The advantages of using this in hydroponics are that it is environment friendly, user-friendly, easily available, disease resistance and has a good adaptability. *Trichoderma* fungus colonises coconut coir, protecting and promoting root development. Because coir has the ideal air-to-water ratio, it is very difficult to overwater; plant roots flourish in this condition. Because coir has a high cation exchange capacity, excess minerals can be stored and delivered to the plant when needed. Coir comes in a variety of forms, the most popular of which is coco peat, which resembles soil in texture and appearance but is devoid of minerals [5].

B. Rice husk/hull: The outer protective layer of rice grains is called as rice hull and plants use them as a substrate or growth medium. During milling, rice hulls an agricultural by-product are extracted from the rice grain. In India, about 20 million tonnes of paddy are produced annually. This gives around 24 million tones of rice husk and 4.4 mil/ion tones of Rice Husk Ash every year. The steel, cement, and refractory brick industries are the three main industries that employ rice husk ash. In India, there are numerous small-scale uses for rice husk, such as feeding cattle and making partition boards, and numerous industrial uses for rice husk ash, such as filling land. However, these applications are not methodical, and rice husk has very little nutritional value. Being fibrous it can prove to be fatal for the cattle feeding. Use of rice husk ash or rice husk in land filling is also an environmentally dangerous means of discarding garbage. India being the second largest rice producer in the world, systematic approach to this material can give birth to a new industrial sector of rice husk ash in India [6]. Due to its unique properties, this material which is frequently regarded as trash in conventional rice processing has found its useful uses in hydroponics. Rice hulls are lightweight, highly porous, have a neutral pH and are considered inert in nature. It is used as growing media, aeration component, seed starting and container gardening. The advantages of using this in hydroponics are that they are readily available, sustainable, has pH stability and provide good aeration and drainage to the hydroponics system. A byproduct of agriculture, parboiled rice husks (PBH) would otherwise be of little use. With time, they deteriorate, allowing drainage and even holding less water than they develop stones. According to a study, rice husks had no effect on plant growth regulators' effects [5].

C. Peat moss: It is a type of organic substance made from partially decomposed sphagnum moss. It is often referred to as sphagnum peat moss. It acts as a growth medium in hydroponic. It helps to support plant roots and makes it easier for nutrients to reach the plants. It's notable characteristics are - it has excellent water retention capacity, good aeration properties, and an acidic pH. In hydroponics, it can be used as growing media, seed starting and container gardening.

D. Almond shells: The outer protective layer of almonds is called as almond shells. Almond shells don't require extensive conditioning treatments before using, because they don't contain any phytotoxic substances in it. To be used as the growth substrate, raw almond shells were first ground into two textures: fine (<4 mm) and coarse (<4.75 mm). These textures were then combined in equal amounts. Its uneven distribution of particle sizes, which allows water to be retained in the medium at different stresses. It has a high salt content. Nitrogen immobilisation in the substrate may have resulted from the almond shell media's high C:N ratio (48) compared to the optimal range for soilless medium (20–40). It has been observed that Nitrogen deficiency cause a reduction in the ratio of shoot to root in plants, as Nitrogen and biomass are directed towards the roots [7].

E. Saw dust: It is an affordable and innovative approach to be used as growing media. It is a by-product of wood processing and good source of organic matter. It has high porosity and fine texture. Because of these physical characteristics, it works well as a part of hydroponic growth medium. Good aeration and water retention are made possible by the porous structure, which creates ideal conditions for root growth. Additionally, the growth media is stabilised by the fine texture.

Physiochemical properties of organic media-

Almond shells, characterized by their high carbon content (72.27%) along with oxygen (22.88%), nitrogen (3.87%), and silicon (0.87%), exhibit a composition rich in cellulose (38.48%), hemicellulose (28.82%), and lignin (29.54%). In comparison, sawdust comprises 40% lignin, 60% cellulose, and minor amounts of waxes, resins, and oils. Despite its low nutrient density, sawdust contains 0.048% nitrogen, 0.007% phosphorus, 0.017% potassium, and 0.106% calcium. Cocopeat, on the other hand, boasts higher nutrient levels with 0.41%, 0.81%, and 1.32% of nitrogen, phosphorus, and potassium respectively. Rice husks contain 1.90% nitrogen, 0.48% phosphorus, and 0.81% potassium, offering a substantial nutrient profile. Peat moss, primarily composed of sphagnum plant remnants, has nitrogen content below 1%, while phosphorus and potassium levels remain below 0.1%. Additionally, it maintains a highly acidic pH ranging between 3 and 4.5. The selection of substrate in hydroponics is vital to maintaining ideal pH levels and giving plants the nutrients they need. Despite having a low nutrient content, almond shells have a balanced mix of cellulose, hemicellulose, and lignin, making them a potential sustainable substrate alternative. Despite having a low nutrient density, sawdust can nevertheless be useful in hydroponic systems because of its cellulose content. Because cocopeat has higher nutritional levels and contains potassium, phosphate, and nitrogen-all of which are necessary for plant growth-it appears to be a suitable substrate. Additionally, rice husks provide a significant nutritional profile that is appropriate for hydroponic growing. Peat moss has an acidic pH and an organic composition, however because of its low nutrient concentration, it might not be the best choice for hydroponics. In hydroponic systems, the selection of substrate should generally be based on a balance of nutrient availability, pH compatibility, and sustainability [7, 11, 12].

Suitable growing media for different crops-

1. Almond shells used in Lettuce production

Almond shells are a practical and economical growing medium that may be used without the need for long conditioning procedures or phytotoxic chemicals, making it a potential option. Almond shells (AS) were bought from Borges Andalucía, a firm that processes almonds in Almería, Spain, and used in a study evaluating the efficiency of almond shells (AS) and perlite (P) for the development of lettuce (*Lactuca sativa* L. cv. Catalogna Verde). The raw almond shells were then ground into two textures: fine (<4 mm) and coarse (<4.75 mm). These textures were then mixed together in an equal amount.

In July 2018, a 13-day germination research was carried out at Newcastle University using a semi-controlled growth chamber to assess the effects of varying growing conditions on Oakleaf lettuce germination. Under a 16-hour photoperiod, the growth chamber was kept at a constant temperature of between 20 and 30 °C. In accordance with the recommendations provided in the Cornell Hydroponic Lettuce Handbook, germination metrics such as percentage, duration, and emergence were evaluated in addition to seedling height and leaf amount. One drip emitter was used per plant for nonrecirculating drip irrigation, with a flow rate of 0.9 L h^{-1} per plant. A solitary 200 L reservoir holding a fertiliser solution was utilised to supply irrigation, ensuring an electrical conductivity (EC) of 1.15–1.25 mS cm^{-1} above the EC of potable water and a pH range of 5.6–6.0.

The study conducted by Valverde *et al*. revealed some disadvantages of the almond shell medium, such as its higher electrical conductivity (EC), insufficient air-filled porosity, and high bulk density. They did, however, point out a key benefit-that it retains water more efficiently than perlite and offers easily accessible water. This is in contrast to the results of a prior study conducted by Urrestarazu *et al*., which pointed up restrictions on the availability and water-holding capacity of almond shells. However, our study's use of smaller almond shell particles made problems like higher bulk density and lower air-filled porosity worse than they needed to be. Therefore, to maximise the potential use of almond shells as a soilless growing medium, the ideal fine to coarse particle ratio has to be found. An alternative method that may be used instead of blending and milling as we did in our study is to prepare almond shells only by blending. With this approach, a coarseness index of 79% may be achieved while guaranteeing that more than 50% of the particles are in the optimal range of 0.25–2.0 mm.

During July 25 and August 1, 2018, there was a drought; some growth medium did not receive any irrigation, while others got

regular watering. Plant stress was measured using stomatal conductance and leaf surface temperatures; greater temperatures and lower conductance corresponded to higher stress. The ability of various growth media to retain water in order to lessen the impacts of drought on plants was assessed. There are not many changes between perlite and almond shells during normal and drought circumstances, according to infrared thermal imaging of lettuce crops cultivated in different medium and irrigation settings. Due to osmotic stress brought on by excessive salinity, almond shells effectively held moisture but did not significantly reduce lettuce stress. Due to osmotic stress brought on by excessive salinity, almond shells effectively held moisture but did not significantly reduce lettuce stress. Though the number of leaves stayed the same, lettuce cultivated in almond shells produced greater yields and root weights than lettuce grown in perlite. Almond shell yields might be further increased in accordance with guidelines for organic waste materials by washing or leaching the medium to lower its salt content before to use. Furthermore, micronutrient levels such as Mn, Zn, and B were greater in lettuce grown in almond shells, perhaps because of the low pH and high concentration of minerals in the medium. As yield can be increased by modifying substrate EC levels, this implies that almond shell media could potentially able to help in maintaining nutritional quality during periods of water scarcity.
Finally, utilising almond shells to grow lettuce requires cautious management to reduce potential stresses and improve growth circumstances. Almond shells have advantages over alternative growing substrates, including greater levels of micronutrients and water retention. In order to fully realise the promise of almond shells as a soilless growth medium, further research may focus on refining processing methods and enhancing irrigation and nutrient management strategies [7].

2. Tomato production in cocopeat

The Department of Soil Science and Water Management is conducting an experiment. The "Growing media for tomato production in hydroponics" was conducted between 2016 and 2017 at the Dr. Y. S. Parmar University of Horticulture and Forestry in Solan, Himachal Pradesh, India. The results of this study indicated that tomato growth, fruit yield, and quality were all highly influenced by the growing medium selection. Vermicompost was added to the media to increase its nutrient content, which improved crop quality and yield. The media's inertness and water-holding ability were also helpful for water use efficiency. Vermicompost and growing media combined provided farmers all over the world with a conveniently available solution and ideal growing conditions. Overall, problems with conventional soil-based tomato cultivation were avoided by using a media blend of cocopeat and vermicompost (70:30) to improve tomato quality and yield in polybags [8]. An experiment on the topic of "Use of Coco peat for soilless cultivation of tomato" was conducted by NK Malviya *et al.*, 2020. They observed that coco-peat showed promising results in improving tomato quality, fruit yield, and vegetative growth. Notable findings included maximum branches per plant (27.50), fruit yield (1.28 kg per plant), and quality indicators such as total soluble solids (TSS), total sugars, and vitamin C content. Vermiculite produced results that were similar. Among the investigated media alternatives, coco-peat also showed strong root growth under Hoagland solution, suggesting its appropriateness as a supporting growing medium for soilless tomato culture [9]. The Hi-Tech Vegetable Center in Punjab conducted an experiment by Singh *et al.* titled "Growth and yield of tomato in soilless media under naturally ventilated polyhouse" with the goal of determining the best growth media and tomato cultivars for protected agriculture in the area. Six tomato cultivars were evaluated in a polyhouse with different media substrates-soil and soilless. Although soilless surfaces proved efficient for problematic soils or soil-borne insect problems, soil was still determined to be the most economically feasible alternative. For the NS-266 cultivar, the cocopeat and vermicompost combination showed the highest benefit-cost ratio and economic yield. Indeterminate tomato cultivars for Punjab were investigated in a study using soilless cultivation. The results showed that the NS-4266 cultivar outperformed the others in terms of yield, and that the maximum fruit yield was obtained with a dose of fertilizer [10]. Studies conducted in several parts of the world indicate that soilless cultivation improves tomato output and growth, especially when employing media based on cocopeat that has been enhanced with vermicompost. Coco-peat has strong performance and provides benefits such enhanced nutrient availability, water retention, and root development. Global farmers profit from the economic viability of soilless solutions, particularly in cases of troublesome soils or pest problems.

Advantages of using crop residue as growing media in hydroponics

An innovative paradigm for attaining effective and sustainable crop production in agriculture is the combination of smart technology with hydroponic systems. Using agricultural waste, such as crop wastes and byproducts like rice husks or coconut coir, into hydroponic growth is a possible way to recycle resources into growing media. For example, using rice hulls as a natural silicon supplement in hydroponic systems offers a more economical and sustainable way to produce capsicum, strengthening the plant's resistance to anthracnose disease and raising the overall development and quality of the fruit [11]. According to the research, the maximum number of leaves was produced when cocopeat was used as the planting material, although it had no discernible effect on the results. On the other hand, the medium containing rice husks showed better root length and dry weight, but no appreciable changes in overall parameters. However, the best medium for height characteristics turned out to be a combination of cocopeat and rice husk [12]. Additionally, studies into sawdust and bag culture hydroponic systems produced better cut flower outcomes and sawdust was shown to be the best growing medium for gypsophila cultures. Adopting such approaches promotes resource sustainability and lessens reliance on synthetic materials, which are in line with environmental conservation and resource efficiency ideals. By enhancing soil structure and stimulating microbial activity, agricultural waste operates as a rich supply of organic matter and nutrients that support the establishment of healthy plants [13]. The Cation Exchange Capacity (CEC) test, which measures the growing medium's nutrient retention capacity, emphasises the importance of materials like cocopeat. These materials efficiently hold onto vital nutrients [14].
Furthermore, by reducing the need for waste disposal, the adoption of agricultural waste as growth media in hydroponic systems can significantly reduce its adverse environmental impact. By reducing the amount of organic waste which accumulates in landfills, this method lowers the greenhouse gas emissions linked to decomposition. This sustainable practice promotes agricultural productivity and sustainability initiatives while advocating for environmentally responsible waste management practices. It also lessens the burden on landfill capacity by turning waste into a valuable resource, which in turn

fosters a circular economy. Some agricultural waste materials, such rice husks or coconut coir, offer higher water retention capabilities and promote sufficient oxygenation of plant roots. The aeration and drainage qualities of these materials are impacted by their texture; fine-textured coco coir is superior in water retention, whereas chunky-textured coco coir offers higher aeration levels and more drainage [14]. Similarly, in hydroponic systems, the pH buffering properties of agricultural waste, such peanut shells and rice husks, assist maintain stable pH levels, maximising plant nutrient absorption efficiency and minimising changes in nutrient availability.

Purchasing commercial substrates is not as cost-effective as using agricultural waste as growth medium, especially for small-scale farmers or beginners looking to maximise plant development while lowering expenses. This approach is a feasible means of improving agricultural production and sustainability since it not only fosters the sustainable utilisation of resources but also offers financial benefits.

Future of using crop residues in Hydroponics

Crop residue utilisation in hydroponic systems offers a diverse strategy for improving nutrient content, increasing resource efficiency, and building ecological resilience in agricultural practices. According to Maharana and Koul (2011), hydroponics offers a glimmer of hope for crop and food production management [15]. Hydroponic systems may efficiently recycle nutrients and lessen their need on external inputs by reusing organic materials that would otherwise be thrown away, reducing waste and maximising resource utilisation. Crop residues boost the nutritional profile of the medium as they break down in the hydroponic solution and release important nutrients including potassium, phosphate, and nitrogen. Because of this natural enrichment, there may be less need for synthetic fertilisers, which would reduce the environmental effects of both their application and manufacturing. Furthermore, crop residues bring a wide range of microorganisms, such as beneficial bacteria, which support the breakdown of organic matter, nitrogen fixation, and disease suppression that are essential to system health.

Futhermore, adding crop residue to hydroponic systems makes carbon sequestration easier and captures carbon that would otherwise be released into the atmosphere through burning or field decomposition. This helps with the mitigation of climate change while also lowering greenhouse gas emissions. Moreover, the application of agricultural waste fosters crop diversity in hydroponic systems as a range of residues from various crops can be included. This diversification lowers the hazards connected with monoculture farming, promotes ecological resilience, and improves the nutritional composition of the food.

Hydroponic systems finish the nutrition loop by using agricultural waste products as useful inputs, according to a circular economy strategy. This approach minimises the production of waste, encourages sustainability, and relates to the circularity and resource efficiency concepts. The circular economy approach implies that the crop production industry in agriculture can achieve greater sustainability by utilising more resources and materials for as long as feasible [16, 17]. A crucial aspect of production systems' sustainability is the need to make them more circular [18]. Farmers may establish environmentally conscious, self-sustaining production systems that optimise productivity and minimise damage on the environment by using agricultural leftovers into hydroponic medium. However, further investigation and development are required to refine processing techniques, determine compatibility with various crop species, and examine long-term effects on soil health and ecosystem dynamics in order to fully realise the potential advantages of this strategy. To promote innovation and the adoption of sustainable farming techniques that maximise the potential of crop leftovers in hydroponic systems, cooperation between scientists, farmers, and policymakers is crucial.

Conclusion

In conclusion, one of the most significant strategies in the development of sustainable food production systems is the use crop leftovers as hydroponic medium. This method provides a solution to many problems in agriculture by recycling agricultural waste into nutrient-rich substrates for hydroponic plants. By making the most of the nutrients and organic materials that are available, it first tackles the problem of resource efficiency by lowering the need for synthetic fertilisers and cutting down on waste. Furthermore, it promotes environmental sustainability by reducing the adverse effects of conventional agricultural methods, such fertiliser runoff and soil deterioration. Crop residue-based hydroponics further supports the circular economy's tenets by encouraging resource efficiency and building agricultural ecosystem resilience. Additionally, as hydroponic systems can be customised to maximise crop yields and reduce water usage in a variety of weather situations, this strategy has a great deal of promise to improve food security and resilience to the impacts of climate change. However, coordinated efforts from a range of stakeholders, including academics, legislators, and farmers, are needed to fully realise the promise of agricultural residue-based hydroponics. Research and innovation are needed to overcome technical issues including nutrition release optimisation and substrate composition optimisation. Furthermore, in order to promote the adoption of sustainable agricultural techniques and make it easier to integrate crop leftovers into hydroponic systems, supporting legislative frameworks and incentives are required. Raising awareness and developing capacity among farmers and communities also requires education and outreach initiatives. The utilisation of crop wastes as hydroponic media presents a convincing approach to a food production system that is more robust and sustainable. This approach depends on the potential of agricultural waste to feed future generations and the world.

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