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An AHP-Based Multi-Criteria Decision-Making Framework for Evaluating Hydroponics Adoption in Sustainable Agriculture in India

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This research evaluates the major factors affecting the adoption of hydroponics in sustainable agriculture practices in India, and it is conducted using the Analytic Hierarchy Process (AHP) method. Data were collected using a designed survey of 35 participants, including hydroponic farmers, agricultural experts, and academicians. The survey was conducted to compare the relative importance of the major factors affecting the adoption of hydroponics. These major factors include technological factors, political and policy factors, environmental factors, social factors, and financial/economic factors. The results of the AHP method showed that technological factors had the highest priority (weight = 0.456). The major factors affecting the adoption in this category are the higher costs of setup and the technical knowledge required. The political and policy factors had the second highest priority (weight = 0.213), which implies the importance of government incentives and policy support. The environmental factors (weight = 0.152) highlight the importance of hydroponics for water conservation. The social as well as the financial/economic factors (weight = 0.066) indicated lower influence on the adoption of hydroponics. Sensitivity analysis validated the stability of the results.

Keywords: AHP, Decision making, Hydroponics, MCDM, Sustainable agriculture

Introduction

Agriculture today is faced with the dual challenge of meeting the food demands of the world and protecting the environment. Conventional farming is no longer considered environmentally friendly because of its high demands for water, fertilizers, and land.[1] Thus, the need to explore and use other sustainable farming methods is being considered worldwide. Among the alternatives to conventional farming is hydroponics. Hydroponics is defined as the controlled cultivation of crops in soil-less systems. Water and nutrients are optimally supplied to the crops. Studies have proven that hydroponics can reduce the use of water up to 90% compared to conventional farming.[2] Thus, hydroponics is considered to have great potential in addressing the issues of global food security and environmental conservation.[3]

Need for Hydroponics Adoption

There are also certain advantages that are unique to this method, and they are more in line with sustainable agriculture. First and foremost, this method does not only conserve water but also allows for high-density cultivation, thus making it more feasible in areas where land is scarce, such as in cities.[4] Furthermore, this method also allows for cultivation indoors or in greenhouses, thus eliminating the need for seasonal weather conditions. In addition, this method also has economic benefits, such as having the potential for more productivity and shorter crop cycles, thus making it more profitable and productive.[5] These advantages make this method more desirable for areas that are having issues regarding food security because this method allows for sustainable cultivation without exhausting natural resources.

Challenges

Despite these advantages, the adoption of hydroponics remains low due to a number of impediments. The first impediment of hydroponics adoption lies in the high cost of setting up the system. In other words, the initial setup cost of hydroponics is high, which might discourage farmers from adopting

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the system.[6] In addition, the adoption of hydroponics faces the impediment of the technical know-how required to control the nutrient levels, control the water, and control the pests. These factors might discourage potential farmers from adopting the system due to the lack of technical know-how.[7] Another impediment of hydroponics adoption lies in the fact that the system requires a consistent supply of electricity as well as well-regulated conditions. These conditions might be difficult to attain, especially in less-developed regions.

Multi-Criteria Decision-Making (MCDM) and Its Relevance

MCDM frameworks have thus become vital tools in fields where complex and multi-dimensional factors need to be evaluated to make informed decisions.[8] In the agricultural sector, MCDM frameworks can help to develop structured approaches to balancing different factors such as environmental factors, cost factors, and technological factors. The use of structured approaches to the problem of hydroponics adoption can help stakeholders to evaluate different multi-dimensional factors to make well-informed decisions.[9] The use of such approaches can help to make comparisons and prioritize each of these factors according to their relative importance. The use of such approaches can help hydroponics stakeholders to make informed decisions about different factors such as economic factors and environmental factors. The use of such approaches can help to pave the way for a balanced approach to sustainable agriculture.

Of the different approaches to MCDM problems, AHP is widely used because of its simple structure and its ability to facilitate pairwise comparisons of different factors in the decision problem. AHP is thus considered appropriate for use in problems where both qualitative and quantitative factors need to be taken into account.[10] By providing experts with the ability to assign different weights to each of the factors and to validate their consistency of judgment, AHP is considered to be a structured approach to solving complex decision problems. Compared to other approaches to solving MCDM problems, AHP is considered to be more appropriate because of its hierarchical modeling and pairwise comparison framework. The use of AHP is considered appropriate because of its ability to allow expert judgment to play a vital role in the evaluation of the problem.

Although advanced AI and machine learning approaches have been gaining popularity in agricultural analytics, they have been considered to be appropriate for use only when large datasets can be obtained. AHP is thus considered to be appropriate as a methodological framework to evaluate and rank the influencing criteria.

Research Gaps and Objectives

Even though hydroponics has been researched in different settings, little has been done in investigating its implementation using an organized decision-making process. To a large extent, the available literature is inclined to devote itself to particular obstacles or a single factor, including the cost of hydroponics or technical specifics, without incorporating them into a single model.[11] The proposed research will fill the gap that an MCDM framework, namely, AHP, would allow to capture the complexities of hydroponics adoption. This strategy is capable of facilitating our knowledge on adoption dynamics and assist decision-makers to adopt strategies that promote sustainable agricultural practices. This study has been prompted by the fact that a decision-making tool that is structured and capable of guiding the policies adopted towards adopting hydroponics would eventually lead to sustainable food production and conservation of resources.

This paper assumes a national level of perspective and it is not specific to agro- climatic zone. The proposed AHP-based model will consider the factors of evaluation of hydroponics adoption that are applicable in a wide area of India and hence may be applied in varied geographical locations such as urban, peri-urban as well as rural agricultural systems.

The research questions of the study are as follows:

RQ1**:** Which are the main criteria that affect the most the introduction of hydroponics in the sustainable agriculture of India?

RQ2**:** What are the ways to design and determine these criteria in terms of an AHP based multi-criteria decision-making model?

RQ3**:** What is the relative significance (priority ranking) of technological, economic, environmental, social, and policy factors influencing the adoption of hydroponics?

Literature Review

The analysis of the available studies on the adoption of hydroponics has been done to determine the appropriate success factors and obstacles. Peerreviewed articles, government reports, as well as case studies in India were included in this review.

The aspects in this research were divided into technological, political, financial, environmental and social aspects. The choice of these categories was due to the fact that the adoption of hydroponics is not only technologically feasible, but also economically feasible, supported by regulations, environmentally sustainable, and socially acceptable. Technological aspects take into consideration the infrastructure and operational abilities needed by hydroponic plants. Financial considerations cover costs of investments, the costs of operations, and the considerations of profitability. Political factors entail policies of the government, subsidies, and regulatory systems that influence adoption. The environmental concerns pertain to the efficiency of resources, water and the effect on the environment. The social aspects are awareness of the farmers, availability of training and how consumers perceive hydroponic produce. All these dimensions offer a holistic approach to the issue of adoption in the perspective of sustainable agriculture in India.

Technological Factors (C1)

- **High Initial Setup Costs (C11):** Hydroponic systems entail high start up costs particularly on infrastructure which restricts its use by small and medium scale farmers.[12]
- **Skilled Technical Knowledge (C12):** Farmers should be educated on how to control the levels of nutrients, lighting and control of pests in hydroponics. These complicated systems need specific expertise and, therefore, access to knowledge will be vital to their adoption.[13]
- **Integration with Renewable Energy (C13):** Hydroponic systems are operated in a manner that may be energy consuming. The use of solar energy or other renewable energy sources can help in cutting down on the cost of operation and reliance on untrustworthy power grids, particularly in rural settings.[14]
- **Availability of Disease–Resistant Crops (C14):** There is an opportunity to have pest-resistant and high-yield varieties of crops bred to grow in hydroponic systems and increase their productivity and lower maintenance expenses.[15]

Political/Policy Factors (C2)

- **Government Subsidies and Incentives (C21):** The government can reduce the financial load on farmers that have shifted to hydroponics by providing financial subsidies either on equipment or offering low-interest loans.[16]
- **Lack of Clear Policy Guidelines (C22):** Hydroponics is a novel industry in India and the absence of a well-defined policy guidelines on licensing, produce certification and market access can pose obstacles to its adoption.[17]
- **Agricultural Extension Services (C23):** Extension services have the potential to offer technical support, troubleshooting and training so that farmers can employ hydroponic systems to a greater effect.[18]
- **Supportive Land Use Policies(C24):** Urban agriculture can be promoted by permitting land and rooftop space to be used in hydroponic farming particularly in urban areas to increase the adoption of hydroponics.[19]

Financial/Economic Factors (C3)

- **High Operational Costs (C31):** There may be high costs of nutrients, seeds, energy, and maintenance, and small farmers may find it hard to maintain hydroponics due to the uncertainty in the prices of their input supply.[20]
- **Market Demand and Profitability (C32):** There must be a stable market, where premium, pesticide free hydroponic produce are valued. Farmers should have an access to products in high demand as in urban centers, hotels, as well as retail chains.[21]
- **Absence of Affordable Financing (C33):** There is limited availability and accessibility of loans and microfinance directly to hydroponic projects and as a result the interested farmers are unable to take loans.[22]
- **Cost of Nutrient Solutions and Materials (C34):** Hydroponic nutrient solutions and materials including LED lighting are also costly, which will add to the recurring costs of hydroponic farming.[23]

Environmental Factors (C4)

- **Water Availability and Conservation (C41):** The use of hydroponics is effective in regions where water is a scarcity since the method does not require a lot of water as compared to other forms of farming. Selling it as being water-efficient would help it gain acceptance in water-stricken areas.[24]
- **Suitability for Urban and Semi–Urban Agriculture (C42):** Fit to Urban and Semi-Urban Agriculture (C42): The small spatial footprint of hydroponics enables urban agriculture, which is

becoming more and more significant in urban areas with limited arable areas.[25]

- **Dependency on Reliable Power Supply (C43):** Hydroponic systems consume much energy in the form of water circulation and lighting thus power supply is always a challenge in some rural locations.[26]
- **Environmental Resilience (C44):** Climate change (droughts, extreme weather, etc.) may be reduced through hydroponics, providing year-round crop production due to the ability to manage the environment.[27]

Social Factors (C5)

- **Consumer Awareness of Hydroponic Produce (C51):** A consumer awareness of the benefits of hydroponically grown produce, including the fact that it is free of pesticides and fresher, can trigger a market demand which consequently increases the profitability of farmers.[28]
- **Community–Based Models for Shared Resources (C52):** Cooperative hydroponic models can enable farmers to share resources and knowledge, limiting the costs and risks per person, and this can also be of assistance to smallholder farmers.
- **Educational Outreach and Skill Development (C53):** A knowledge gap can be closed by providing educational programs to farmers on the techniques of hydroponic farming. The collaboration with universities, NGOs, and the private companies can be used to raise awareness and expertise.
- **Youth Engagement and Employment Opportunities (C54):** Youth Engagement and Employment Opportunities (C54): Hydroponics presents employment opportunities to youths who are interested in agriculture and technology in which a new labor force in the sector would be created.

Methods

The paper will apply a MCDM model based on the AHP[29] to assess the determinants of adoption in hydroponics of sustainable agriculture. The research methodology used is the AHP due to its capability of addressing complex decision making situations where many criteria are involved and revealing the ability of the research method to make a structured comparison of qualitative and quantitative factors.[30,31] Fig. 1 illustrates the research methodology followed.

The AHP based Framework development

Step 1: A hierarchy of AHP was created as Fig. 2 below including:

- **Goal:** How successfully is hydroponics used in sustainable agriculture?
- **Criteria:** Critical variables of adoption (as literature revealed).
- **Sub–criteria:** Detailed sub-criteria within each criteria (e.g. within technological there is initial costs, technical knowledge and crop availability).

Step 2: Sample selection

Stratified random sampling technique was employed to sample a heterogeneous sample of all stakeholders dealing with hydroponics who included:

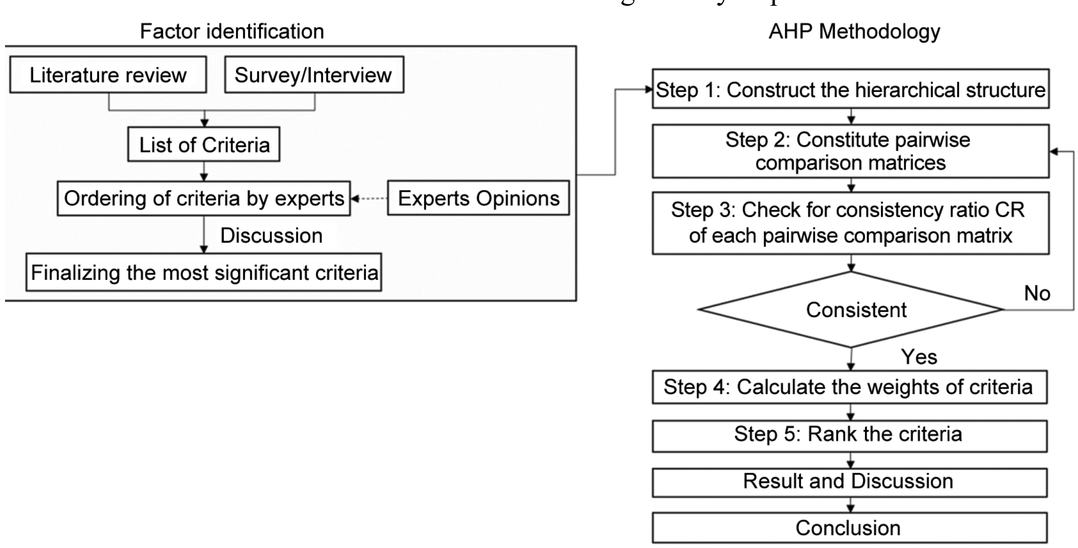

Fig. 1 — Research methodology

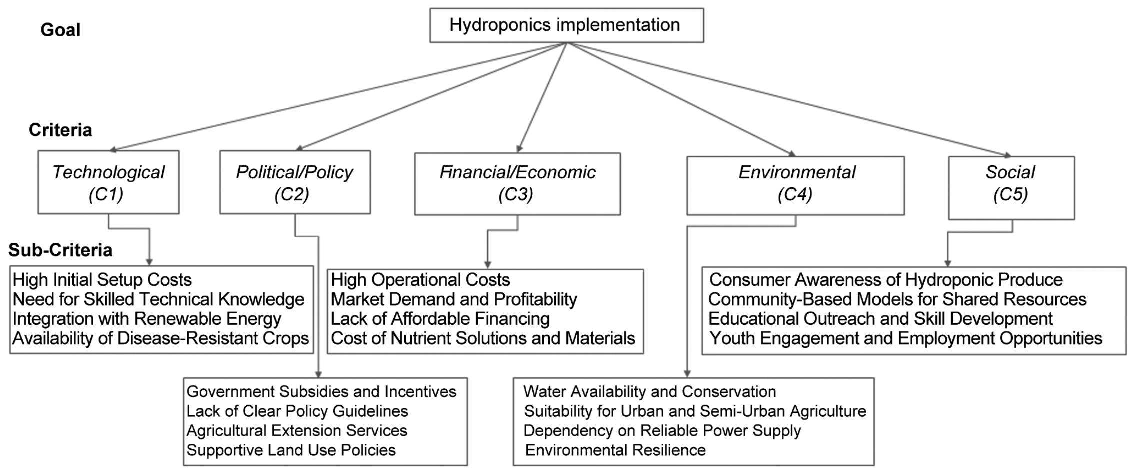

Fig. 2 — Hierarchical structure of hydroponics implementation

- Farmers engaged in hydroponics
- Agricultural experts
- Academicians/Researchers

The target sample size was determined to be 35 respondents in order to have statistical significance and variety of views. The aim of the online survey was to collect data on the following: demographics, perceived factors of success and obstacles to the adoption of hydroponics, and reactions to pairwise comparisons. The pilot-test approach was applied to the survey to test the questions and make them clear to the participants.

Step 3: Preparation of pair–wise comparison matrix.

To systematically evaluate the relative importance of various factors influencing hydroponics adoption, a pairwise comparison matrix was constructed. The comparisons were conducted using Saaty's nine-point scale, where values from 1 to 9 represent equal importance to extreme importance of one criterion over another as shown in Table 1. Based on these judgments, pairwise comparison matrices were constructed and normalized to derive the priority weights of each criterion.

Let C_1, C_2, …Cn denote the factors influencing hydroponics adoption. The pairwise comparison matrix A_1 can be represented mathematically as follows:

$$A1=\begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \dots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \dots & a_{3n} \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \dots & 1 \end{bmatrix} \quad \dots (1)$$

Table 1 — Level of preference weight

Value	Preference
1	Preferred Equally with other alternative
3	Preferred Moderately over other alternative
5	Preferred Strongly over other alternative
7	Preferred Very strongly over other alternative
9	Preferred Extremely over other alternative

Table 2 — Random consistency index

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.5

Each element a_{ij} in the matrix represents the relative importance of criterion Ci compared to criterion Cj on a scale as shown in Table 1.

Step 4: Matrix consistency checking

AHP also has a consistency check that determines the reliability of the pairwise comparisons. In case inconsistencies are found, decision-makers might have to change their judgments to enhance the consistency.

Step 4.1 Calculate Geometric Mean alternative wise.

Step 4.2 Normalize weight matrix, each value is divided by the sum of the values to obtain A2 Matrix.

Step 4.3 Calculate weighted A1 matrix and name it as A_3 matrix ($A_3 = A_1 \times A_2$)

Step 4.4 Determine weighted normalized A3 matrix and it is called A4 matrix (A4 = A3/A2).

Step 4.5 compute Consistency Index and ratio by equation (5) in Table 2.

$$CI = (\lambda\_max - n) / (n - 1) \quad \dots (2)$$

When the index of consistency is above 0.1, then you are not consistent in your statements of pair-wise comparison. Then alter original pairwise comparison table and repeat Consistency ratio.

Results & Discussion

The findings of this research give a full review of the aspects that determine the adoption of hydroponics in sustainable farming. Technological factors were the most important ones as their weight was 0.456 showing the importance of technical infrastructure and specialized knowledge in the adoption of hydroponics. The major barrier was found to be high initial set up costs as shown in Table 3, as the initial set up costs needed to initiate a hydroponic infrastructure, equipment and technology is very high. Small- and medium-scale farmers are prohibited by this financial burden. Also, technical knowledge requirements, including nutrient balancing and pest management, also limit accessibility especially to potential adopters with limited resources as demonstrated in Table 4 and Table 5.

The second category of most influential identified by the analysis was political and policy factors with a weight of 0.2133 which stressed the role of government support or inclusion of subsidies, regulatory frameworks, and extension services to encourage the adoption of hydroponics. An explicit policy and government subsidies can greatly help to lower the barricading costs and this will make hydroponics systems available to more farmers. Thirdly, the environmental factors were given a weight of 0.152 in recognition of the sustainability of hydroponics, especially in water conservation. The fact that hydroponic systems conserve water usage is in tandem with the idea of sustainable agriculture and this methodology would be highly applicable in arid areas and urban areas with sparse arable land.

Table 3 — Pairwise Comparison Matrix for main categories

Fact.	C1	C2	C3	C4	C5	**Weight**
C1	1.00	3.00	5.00	4.00	3.00	**0.456**
C2	0.33	1.00	3.00	2.00	2.00	**0.213**
C3	0.20	0.33	1.00	0.50	0.33	**0.066**
C4	0.25	0.50	2.00	1.00	3.00	**0.152**
C5	0.33	0.50	3.00	0.33	1.00	**0.113**

Table 4 — Pairwise comparison matrices for subcategories

1. Technological Factors (C1)

	C11	C12	C13	C14	**Weight**
C11	1	3	5	2	0.472
C12	0.33	1.00	3.00	0.50	0.170
C13	0.20	0.33	1.00	0.25	0.073
C14	0.50	2.00	4.00	1.00	0.285

2. Political/Policy Factors (C2)

	C21	C22	C23	C24	**Weight**
C21	1	2	3	4	0.447
C22	0.50	1.00	2.00	3.00	0.266
C23	0.33	0.50	1.00	2.00	0.153
C24	0.25	0.33	0.50	1.00	0.091

3. Financial/Economic Factors (C3)

	C31	C32	C33	C34	**Weight**
C31	1	2	3	4	0.467
C32	0.5	1	2	3	0.278
C33	0.33	0.5	1	2	0.160
C34	0.25	0.33	0.5	1	0.095

4. Environmental Factors (C4)

	C41	C42	C43	C44	**Weight**
C41	1	3	2	4	0.467
C42	0.33	1	0.5	2	0.160
C43	0.5	2	1	3	0.278
C44	0.25	0.5	0.33	1	0.095

5. Social Factors (C5)

	C51	C52	C53	C54	**Weight**
C51	1.00	2.00	3.00	4.00	0.47
C52	0.50	1.00	2.00	3.00	0.28
C53	0.33	0.50	1.00	2.00	0.16
C54	0.25	0.33	0.50	1.00	0.10

Table 5 — Global weights and rank

1. Technological factors (C1)						
	C11	C12	C13	C14	Global weight	Rank
C11	1.00	3.00	5.00	2.00	0.215	1
C12	0.33	1.00	3.00	0.50	0.077	4
C13	0.20	0.33	1.00	0.25	0.033	9
C14	0.50	2.00	4.00	1.00	0.130	2
2. Political/Policy factors (C2)						
	C21	C22	C23	C24	Global weight	Rank
C21	1.00	2.00	3.00	4.00	0.095	3
C22	0.50	1.00	2.00	3.00	0.057	6
C23	0.33	0.50	1.00	2.00	0.033	10
C24	0.25	0.33	0.50	1.00	0.019	14
3. Financial/Economic factors (C3)						
	C31	C32	C33	C34	Global weight	Rank
C31	1.00	2.00	3.00	4.00	0.031	12
C32	0.50	1.00	2.00	3.00	0.018	15
C33	0.33	0.50	1.00	2.00	0.011	19
C34	0.25	0.33	0.50	1.00	0.006	20
4. Environmental factors (C4)						
	C41	C42	C43	C44	Global weight	Rank
C41	1.00	3.00	2.00	4.00	0.071	5
C42	0.33	1.00	0.50	2.00	0.024	13
C43	0.50	2.00	1.00	3.00	0.042	8
C44	0.25	0.50	0.33	1.00	0.014	17
5. Social factors (C5)						
	C51	C52	C53	C54	Global weight	Rank
C51	1.00	2.00	3.00	4.00	0.053	7
C52	0.50	1.00	2.00	3.00	0.031	11
C53	0.33	0.50	1.00	2.00	0.018	16
C54	0.25	0.33	0.50	1.00	0.011	18

Although the influence of social factors is not as critical as a whole, they are necessary to determine the demand and perception of consumers on the market. Market demand believes can be spurred by consumer awareness and this subsequently can be adopted by farmers. Lastly, financial and economic reasons were at the bottom with the weight of 0.066, as it is essential to have easy access to the financing options to offset the initial and operating cost of the hydroponics. A high instance of setup costs as well as recurring costs can be a major obstacle to adoption especially in areas that have little access to microfinance or specialized loans.

It is an AHP-based framework, which suggests systematic prioritization of factors that affect hydroponics adoption. The results highlight that specific support measures, including financial incentives supported by the government, technical education, and awareness among the population, are necessary to eliminate the greatest obstacles and encourage the mass use. These findings highlight the necessity of the cooperation between governmental and educational establishments and private sector stakeholders to make hydroponics adoption.

Sensitivity Analysis

In the sensitivity analysis of factors that affect the adoption of hydroponics, technological factors always take the first position, and their position has been maintained even with changes of $\pm$10-30. It means that technological issues are highly prioritized and will serve as the major obstacle in diverse situations. The second most influential is political/policy factors, which highlight the relevance of adopting the political/policy factors in lessening the hurdles to adoption with the help of enabling government policies and subsidies. Environmental factors are a bit sensitive, small changes in the order of priorities, and their effect may be different due to changes in weights, but it is still very relevant.

Social and financial/economic factors, in turn, are proven to be more sensitive. As long as they are reduced in their weights, these factors are even lower

Table 6 — Sensitivity Analysis

	10%	20%	30%	–10%	–20%	–30%
C1	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5
C2	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C3>C2>C4>C5
C3	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C4>C3>C5
C4	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C4>C3>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5
C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5	C1>C2>C3>C4>C5

in priority, however, when the weights are raised, they are sometimes given a higher priority than the environmental factors. It indicates that although the social awareness and the accessibility of financing have a minor role in the baseline model, they can have a greater role under a specific set of conditions. Such sensitivity analysis allows concluding that the flexibility of policy and financial support strategy is needed, because although technological and policy support can be considered background, specific increases in the levels of social acceptance and financial resources may positively influence the prospect of adoption in diverse circumstances. The ranking under various situations as given in Table 6 indicates that there is stability of the model at various values of weights.

Practical Implications

The conclusions of this paper have a number of practical implications to the development of hydroponics use in sustainable agriculture. To start with, since the technological factors are of high significance, it should reduce the initial setup costs and offer technical training to enable hydroponics become more affordable. The governments and agricultural agencies can create specific financial support programs like subsidies or grants that would offset these high initial costs. The collaboration with technology providers to provide inexpensive equipment or lease arrangements may also be efficient in lessening obstacles, and make hydroponics a feasible option to small- and medium-scale farmers.

The research also emphasizes the policy support that is important in the adoption of hydroponics. It is possible to improve adoption by formulating clear supportive regulations and guidelines to hydroponic farming by the policy makers. Financial barriers can also be mitigated by introducing incentives, such as tax breaks or subsidies on interests on hydroponic projects. The formation of agricultural extension services based on hydroponics would equip the farmers with the necessary knowledge and training and resources, which is vital to the proper management of these systems. The knowledge gaps can also be addressed through such support so that farmers can operate and maintain hydroponic setups with a lot of confidence.

Another major practical implication is the increasing consumer awareness and demand of hydroponic produce. The demand can be aroused with educational campaigns that will emphasize the advantages of hydroponic produce, e.g.: it is pesticide-free and fresh. This demand can encourage more farmers to become hydroponic farmers which will lead to a positive cycle of adoption due to the interest of the consumer. Hydroponic produce could also be made more accessible in the market through retail partnerships that give special consideration to hydroponic produce and enhance the profitability and scalability of hydroponics. Finally, financial institutions can also become influential and create available financing paths, which would be specific to the particularities of hydroponic farming. This involves providing low interest loans or microfinance facilities to assist in set up and running expenses. Cooperation among financial institutions, government agencies and the involvement of non-governmental organizations in developing sorts of financing models that can serve the smallholder farmers and urban farmers would go a long way in increasing the uptake rates.

Through the strategies, the stakeholders are able to create a favorable environment to support the growth of hydroponics and sustainable agricultural activities that would enhance conservation of resources, food security, and development of urban areas.

Conclusions

This paper used AHP to assess the aspects that determine the adoption of hydroponics in sustainable agriculture in India. The analysis created a quantitative prioritization of decision criteria. Technological aspects accounts had the largest weight in the world (0.456), meaning that infrastructure facilities, technological preparedness, and technical skill are the most significant in the adoption of hydroponics. Initial high costs of set up and special expertise operations are some of the major barriers to technology. The second reason (0.213) was political and policy-related, as it indicated that government incentives, subsidies, and regulatory support were important in making the adoption easier. Environmental concerns were considered third (0.152) focusing on the benefits of hydroponics as per water-use efficiency and its lesser dependence on land. The social factors were found to have a moderate impact, especially in matters regarding growing awareness and demand on pesticide-free produce among consumers and financial factors were least in terms of weight (0.066).

The study however has limitations. The AHP analysis is also based on the expert judgment which can make it subjective and restrict the generalizability of the overall results. Also, the research is based on using a narrow range of criteria and a particular decision-making model. Future studies can build upon this study by adding a greater sample of experts, combining other methods of multi-criteria decision-making, and obtaining empirical research to validate the results with empirical research that involves studies conducted in the field that implement hydroponic adoption in various parts of India.

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