RESEARCH ARTICLE

Harnessing the Role of Scientoon (Scientific Cartoon) in promoting Hydroponics: Empowering Farmers for Sustainable Agricultural Practices

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Abstract

The study investigated the effectiveness of Scientoon, which is a visually engaging, science-based cartoon designed to communicate scientific concepts, along with other underlying factors that influence awareness and willingness to adopt hydroponics among rural people. A series of Scientoon was developed focusing on the benefits of hydroponics and presented to rural people. To assess the change in level of awareness, a sample of 390 respondents was gathered through pre and post-session surveys and interviews. To analyze the data of the study, descriptive statistics, the Probit model, and the McNemar test were utilized. The result of the Probit model revealed a significant and positive impact of the Scientoon-based intervention on awareness and willingness to adopt hydroponics. The McNemar test $\chi^2 = 173.63$, $p < 0.001$ also confirms a meaningful positive change in awareness post intervention of Scientoon. The study demonstrates the potential of Scientoon as a cost-effective tool for science communication and agriculture extension in low-literacy rural areas. It also offers insights for future interdisciplinary research in rural development. This is one of the pioneer studies to evaluate the impact of the Scientoon in promoting sustainable agriculture practices like hydroponics, demonstrating their implication in rural extension efforts.

Highlights:

- The study explores how Scientoon (scientific cartoon) can effectively promote awareness and adoption of hydroponics among rural communities.
- Conducted among 390 respondents and it showed a significant increase in the level of awareness post-intervention of Scientoon (McNemar test $\chi^2 = 173.63$, $p < 0.001$).
- Probit model results showed that gender ($\beta = 0.373^*$), education ($\beta = 0.480^{**}$), exposure to Scientoon ($\beta = 1.596^{***}$), and occupation had a strong positive impact on awareness, while age had a small negative but insignificant effect.
- The study recommends integrating Scientoon into agriculture extension and awareness programs to promote sustainable farming practices like hydroponics.

Keywords: Hydroponics, Sustainable agriculture practice, Scientoon, Awareness, Cost-effective

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Introduction

Agriculture serves as the pillar for rural communities, playing an essential role in sustaining livelihoods, ensuring food security, and driving local economies (Tshikovhi *et al.,* 2023; Kumar, 2024). For millions of rural families, agriculture is more than just work- it is a way of life, deeply connected with their cultural and social traditions. As the main source of income in rural areas, any challenge in the agriculture sector can significantly affect their quality of life (Nazir *et al.,* 2024). Although marginal and smallholder farmers constitute 86.2% of all Indian farmers, they only control 47.3% of the country's arable land, whereas semi-medium and medium farmers, who represent only 13.2%, control 43.6% of the country's cropland (Agriculture Census Division, 2019). It has been predicted that the global population will exceed 9.7 billion by 2050 (Rubert *et al.,* 2024), placing enormous pressure on the world's food systems. Alarmingly, nearly 50% of the world's arable land is projected to become unsuitable for farming due to factors such as climate change, soil degradation, and urban expansion (Khan *et al.,* 2020). This growing challenge makes the efficient and productive use of remaining farmland not only crucial for meeting food demand

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but also vital for eradicating rural poverty (Ivanic and Martin, 2018; Olsson *et al.,* 2023). With this situation in mind, there is an urgent need to find new approaches for advancing agricultural practices in a way that could enhance food production, improve resource management, and the economic welfare of rural farmers.

One such innovative solution to address this need is hydroponic farming, a soilless cultivation method that offers significant advantages over traditional soil-based farming (Khatri *et al.,* 2024). Hydroponics has the capacity to improve the productivity as well as sustainability of crops, especially in regions with poor soil, irregular rainfall patterns, or low availability of water (Szekely and Jijakli, 2022). The declining availability of arable land and water resources for irrigation has further increased the need for hydroponics as an alternative solution to traditional farming to solve the issues of food security and support smallholder farmers in rural areas (Naresh *et al.,* 2024).

Although hydroponics offers several promising advantages, it remains an unknown idea to most rural farmers. They do not even have basic knowledge about these kinds of innovative farming practices, which depicts a significant awareness gap and a lack of scientific understanding. Existing literature on hydroponics largely focuses on technical design, adoption challenges, and agronomic benefit (Gillani *et al.,* 2023; Naresh *et al.,* 2024; Fuentes-Peñailillo *et al.,* 2024) but does not examine how communication strategies can bridge awareness gaps among low-literate rural communities. According to Srivastava (2011) and Srivastava et al. (2020), a possible solution to address this awareness gap is the use of Scientoon, a science-based cartoon designed to convey complex scientific information through simple, humorous, and visually appealing illustrations. Unlike infographic or technical illustrations that primarily present information in structured or graphical formats, Scientoon incorporates humor and storytelling, making the information more relatable and easier to understand. Building on this idea, Srivastava (2011) describes *Scientoonics* as an emerging discipline aimed at enhancing scientific communication through the systematic use of Scientoon as an innovative and interactive educational tool. Scientoon utilizes visual storytelling to elucidate complex concepts (Trnová *et al.,* 2013), rendering it an optimal medium for familiarizing rural communities with low literacy levels about sustainable agricultural practices such as hydroponics. Prior studies have also demonstrated the usefulness of visual communication tools such as comics and Scientoon in communicating scientific ideas (Nath, 2018; Srivastava et al., 2020; Badeo and Koc, 2021). Very limited research has explored their application in the context of agricultural extension, particularly for promoting complex and technology-driven practices like hydroponics. To our knowledge, no empirical study has yet examined its use in improving awareness or willingness to adopt sustainable agricultural practices such as hydroponics among farmers using both qualitative insights and statistical analysis. Therefore, the primary objective of the study is to address this gap by evaluating, for the first time, the effectiveness of Scientoon-based intervention on the awareness and willingness of rural respondents to adopt hydroponics, thereby offering a novel interdisciplinary contribution to science communication and sustainable agriculture.

The research article is divided into six sections, starting from the introduction and ending with the conclusion. The second section gives foundational insights and background on hydroponics and underscores the need for Scientoon in its promotion among farmers. Possible research methodology, area of study, econometric model estimated, and non-parametric test are discussed in the third section. This section also covers the estimation methods, variable measurements, and their probable effects. The fourth section presents the findings of descriptive statistics, econometric models, and non-parametric tests. The fifth section discusses the results to measure the change in the level of awareness on hydroponics post-intervention of Scientoon. The final and six portions summarize key outcomes, practical implications and recommendations.

Foundational Insights and Background

In rural areas, where farming often faces various challenges such as land degradation caused by excess use of chemical fertilizers and pesticides or low yields due to climatic situations, hydroponics allows crop production in a limited area and less water utilization (Naresh *et al.,* 2024). The technique can be practiced even in small landholding areas, like greenhouses or even in a house, thus it can be a good option for small and marginal farmers who hold less land.

Pathak *et al.* (2022) have also observed that, in eastern Uttar Pradesh, 57.91% of the farmers have less than 1 hectare of land owned by each, which provokes the adoption of hydroponic techniques in farming, by which small and marginal farmers can also maximize their crop production tremendously. Additionally, hydroponics also enables year-round cultivation, mitigating the risks of seasonal crop failures and ensuring a steady source of income for farmers (Verma *et al.,* 2023; Kumar, 2024).

The nutrient solutions used in hydroponics contain all essential minerals (Table 1) like nitrogen, potassium, phosphorus, calcium, magnesium, and other trace elements, and they can be customized to meet the unique requirements of certain crops, thereby enhancing growth and productivity (Al Meselmani, 2022; Fuentes-Peñailillo *et al.,* 2024). For small and marginal farmers, hydroponic techniques can be a cost-effective method because it reduces dependence on chemical fertilizers and pesticides, promoting more sustainable agriculture practices (Sharma and Bipana, 2024).

Different types of hydroponic systems

There are several hydroponic systems available for the individual who practices it, the choice of system depending on the type of plant being grown. While the initial setup costs may be higher, hydroponics can lead to increased crop productivity in limited land spaces, making it economically feasible in the long term. The most extensively used hydroponic methods are shown in Fig. 1.

Wick System

A passive and easy hydroponic system in which plants are maintained in an inert medium (Fig. 1a) through which the nutrient solution is transported to the roots by a cotton rope wick (Velazquez-Gonzalez *et al.,* 2022).

Table 1: Essential minerals for hydroponics with their source and function

S.No.	*Minerals*	*Source*	*Function*	*References*
1.	Nitrogen (N)	Ammonium nitrate (NH_4NO_3)	Protein synthesis, leaf development, and overall plant growth	Rajaseger *et al.,* 2023
2.	Potassium (K)	Potassium sulphate (K_2SO_4)	Supports overall plant health	Al Meselmani, 2022
3.	Boran (B)	Boric acid (H_3BO_3), Borate ($(BO_3)^{3-}$)	Pollen formation and cell division	Al Meselmani, 2022; Rajaseger *et al.,* 2023
4.	Phosphorus (P)	Monopotassium phosphate (KH_2PO_4); Dihydrogen phosphate ($H_2PO_4^-$)	Enhances root development and flowering	Al Meselmani, 2022; Rajaseger *et al.,* 2023
5.	Manganese (Mn)	Manganese ions (Mn^{2+} and Mn^{4+})	Required for photosynthesis	Al Meselmani, 2022; Rajaseger *et al.,* 2023
6.	Calcium (Ca)	Calcium-nitrate ($Ca\ (NO_3)_2$)	Strengthens cell walls	Rajaseger *et al.,* 2023
7.	Molybdenum (Mo)	Molybdate (MoO_4^{-2})	Required for nitrogen fixation and enzyme activity	Rajaseger *et al.,* 2023
8.	Magnesium (Mg)	Magnesium-sulphate ($MgSO_4$)	Vital for chlorophyll production	Al Meselmani, 2022; Rajaseger *et al.,* 2023
9.	Iron (Fe)	Iron chelate	Aids in chlorophyll formation	Rajaseger *et al.,* 2023
10.	Zinc (Zn)	Zinc ions (Zn^{2+})	Crucial for enzyme activation & hormone regulation	Rajaseger *et al.,* 2023

Aeroponics

This is an advanced system of plant culture in which nutrient-rich water is provided to the roots of the plant in the form of aerosol (Fig. 1b) with the aim of high utilization of oxygen and nutrients (Santosh and Gaikwad, 2023).

Drip Irrigation System (DIS)

This technique uses tubes to transfer water from a tank to the plants (Fig. 1c), which saves water and ensures proper distribution of water (Sharma *et al.,* 2018; Dubey and Nain, 2020).

Deep Water Culture (DWC)

It is also referred to as the floating root system; this technique consists of immersing the root system of a plant in a nutrient solution while the plant is held by support materials (Fig. 1d), *e.g.,* polystyrene or cork above the water (Gillani *et al.,* 2023).

Nutrient Film Technique (NFT)

In this method, the roots of the plants are partially submerged in a thin layer of flowing nutrient solution in a pipe (Fig. 1e). Excess solution returns to the tank by gravity and the flow is either constant or can be stopped and started at intervals (Mohapatra *et al.,* 2020; Gillani *et al.,* 2023).

Ebb and Flow System

Plant roots are submerged in the nutrient solution and drained back to a reservoir at regular intervals (Fig. 1f). Thus, continually fed with nutrients and oxygen (Rajaseger *et al.,* 2023; Sousa *et al.,* 2024; Fuentes-Peñailillo *et al.,* 2024).

Aquaponics

This method is a combination of hydroponics and aquaculture (Fig. 1g), which involves using waste from fish as a natural fertilizer in the system to grow plants. In return, plants themselves act as bio-filters, cleaning or purifying the water before it is recycled back to the fishponds (Khatri *et al.,* 2024).

Application of Scientoon in Agriculture

The application of Scientoon in agricultural education is not a novel event; however, its application in promoting hydroponics among the less-literate rural population is an early empirical work. Evidence from related fields suggests that visual teaching aids are potent tools for influencing knowledge (Rodriguez and Lin, 2016) and behavioral change (Cohen *et al.,* 2024). A study by Nath (2018) highlights the crucial function of Scientoon in advancing the applications of nanotechnology. Scientoon utilizes imaginative and perceptive illustrations to convey complex scientific concepts (Srivastava et al., 2020), making nanotechnology more approachable and interesting (Nath, 2018). Similarly, Shukla *et al.* (2025) have also utilized the Scientoon in the dissemination of heavy metal toxicity on the germination of wheat plants. Collectively, these examples highlight the transformational capacity of Scientoon in enhancing awareness, influencing behavior, and decision-making within agricultural and scientific communities.

Research methodology and framework

The study adopted a structured methodology to investigate the effectiveness of the Scientoon-based intervention in promoting hydroponics among the rural population of the Bahadurpur block of Prayagraj district, Uttar Pradesh. The methodology starts with outlining the conceptual framework and identifying the research gap. Based on that, the research design was structured, and research objectives and hypotheses were formulated. After that, the comic was developed with the help of Scientoon as a primary communication tool for the intervention. Furthermore, the section also explains the justification for selecting the geographical area of the present study, followed by sources and methods of data collection, the procedure of sampling, determining sample size, and data analysis. Overall, this section clearly explains how the study was designed, how

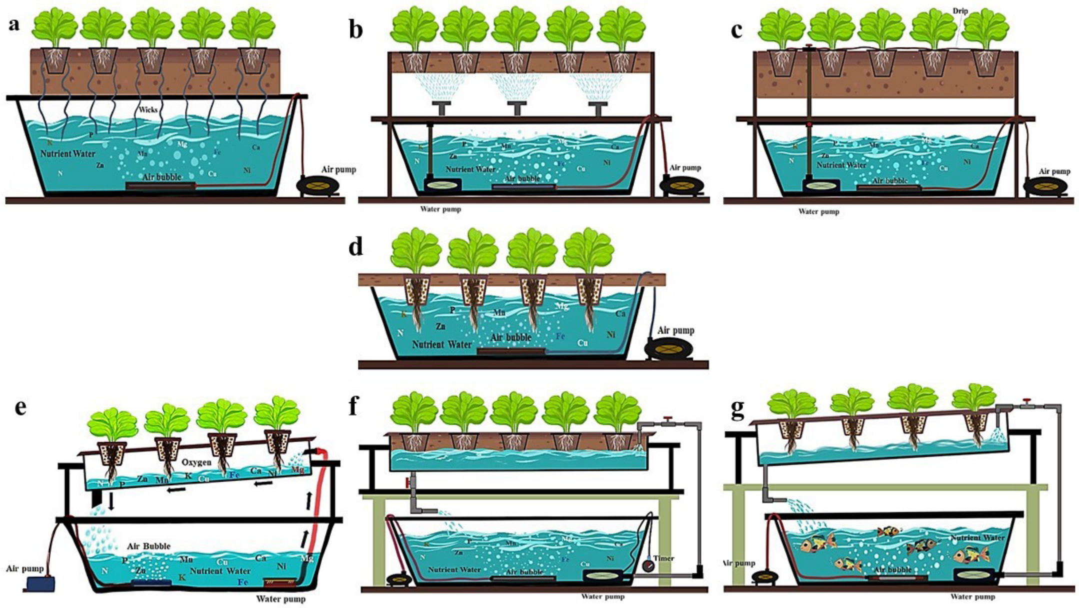


Fig. 1: Pictorial depiction of the most extensively used hydroponic methods: a. Wick system, b. Aeroponics, c. Drip irrigation system (DIS), d. Deep water culture (DWC), e. Nutrient film technique (NFT), f. Ebb and Flow system, g. Aquaponics

the sample was selected, and how the data were gathered and analyzed to achieve the objective of the study.

Conceptual framework

The conceptual framework serves as the foundation for the econometric technique utilized here for the first time to investigate the role of Scientoon in the promotion of hydroponics (Fig. 2). The adoption of innovative agriculture practices like hydroponics by farmers is contingent upon the anticipated advantages of these methods in terms of comparative budget and return (Asule *et al.,* 2024). Its adoption outcomes include food security, environmental sustainability, improved farm income, less water usage, and faster plant growth (Szekely and Jijakli, 2022; Naresh *et al.,* 2024). It is assumed that the adoption of modern agriculture practices like hydroponics by farmers is impacted by a variety of factors, including financial advantages, environmental advantages, awareness, and education level, *etc.*

In the present paper, the conceptual framework attempts to identify the role of Scientoon (scientific cartoon) in the promotion of hydroponic techniques among diverse rural audiences, including rural women and farmers with limited education. Scientoon is an engaging and effective medium for bridging the gap of awareness (Nath, 2018; Srivastava, et al., 2020) by combining the visual with scientific content of hydroponics. The conceptual framework for this initiative involves three main components: content development, community engagement, and impact evaluation. The content development focuses on creating visually compelling Scientoon that illustrate the principles and benefits of hydroponic techniques in a culturally and linguistically relevant manner. Community engagement is achieved through interactive sessions by leveraging the power of visual storytelling to connect with rural people. Impact evaluation involves assessing changes in the level of awareness and willingness towards the adoption of hydroponics through pre and post-intervention surveys (Fig. 2).

Design of Research

A mixed-method approach was used in the research design, integrating both qualitative and quantitative techniques to give a thorough grasp of how well Scientoon promotes hydroponics among rural people. A random sampling method was adopted to choose the respondents. The purpose of the research was to measure changes in knowledge, attitudes, and behaviors towards the adaptation of hydroponic techniques in farming.

Development of comics to spread awareness about hydroponics

A comic was developed with the help of Scientoons to promote hydroponic methods of farming and create awareness among rural populations, including less-literate farmers (Supplementary Fig. 1). These Scientoons were developed using Autodesk SketchBook version 5.1.0 and MS PowerPoint 2016 version 14.0.4734.1000.

Study Area

The study was conducted in three villages, Ramapura, Maheshpura, and Sherdeeh, located in the Bahadurpur block of Phulpur tehsil in the Prayagraj district of Uttar Pradesh, India (Fig. 3a-c), to allow more controlled implementation of the Scientoon-based intervention and to get reliable results. According to the 2011 statistics of the Indian census, the district has 5.95 million people with a population density of 1,086 persons/sq.km, of which 75.3% reside in rural areas in 3,053 villages spread among 23 blocks and 8 tehsils. The overall literacy rate of the district is 72.3%, while the rural literacy rate is 68.8%. The district's Multidimensional Poverty Index (MPI) of

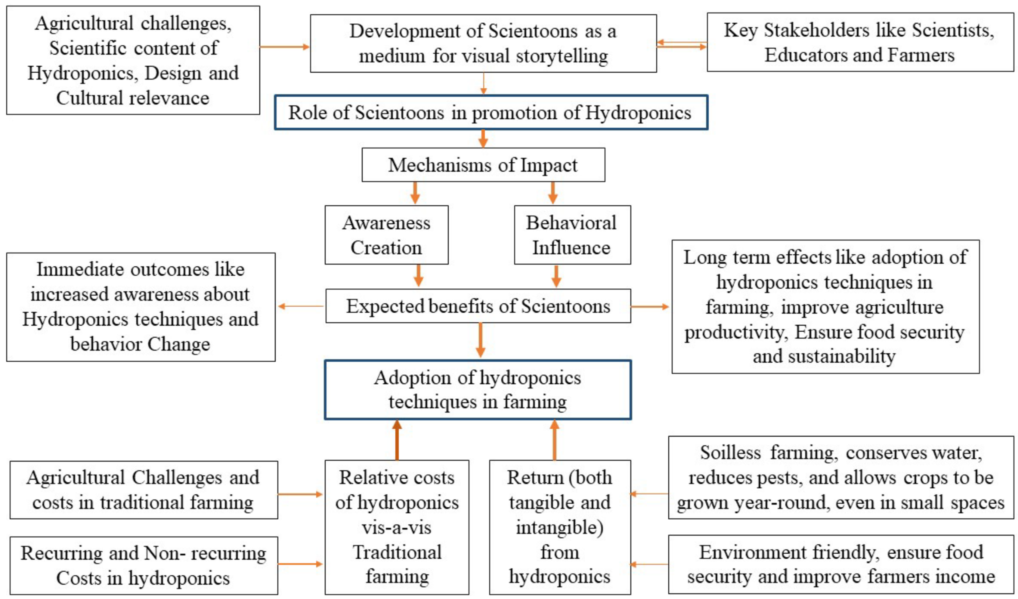


Fig. 2: Conceptual framework for adoption of hydroponic techniques in farming and the role of Scientoon (scientific cartoon) in their promotion

0.153 and a Headcount Ratio of 32.7% in 2016 suggest significant levels of poverty. As per the Census of India (2011) reports, about 28.7% of rural populations are cultivators and 32.1% agricultural laborers, demonstrating their dependence on agriculture.

Bahadurpur is one of the 23 blocks located in the fertile Indo-Gangetic Plains, but the majority of residents have no agricultural land. Farmers are small or marginal, with fragmented land holdings, and face challenges such as limited agricultural extension services, water scarcity, and dependence on traditional farming practices. Despite the need for alternatives, awareness of modern sustainable farm techniques, such as hydroponics, remains minimal. These conditions make an ideal environment to select the villages of Bahadurpur as a study area for evaluating Scientoon-based intervention, as the tool can effectively convey the benefits of adopting hydroponics in a simplified, effective, visually engaging, and relatable manner to the less literate rural population, where the traditional extension methods often face engagement barriers (Fig. 3).

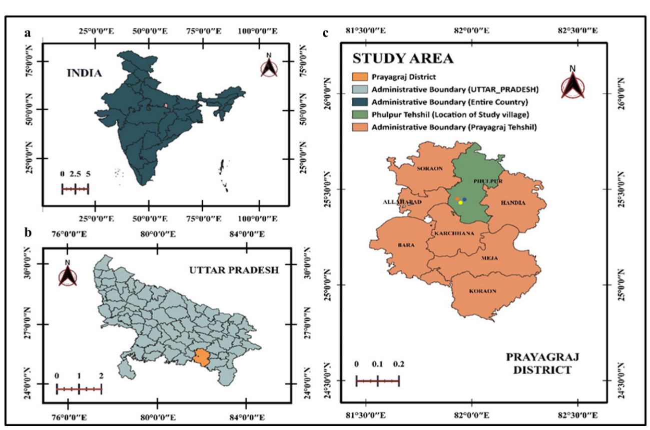
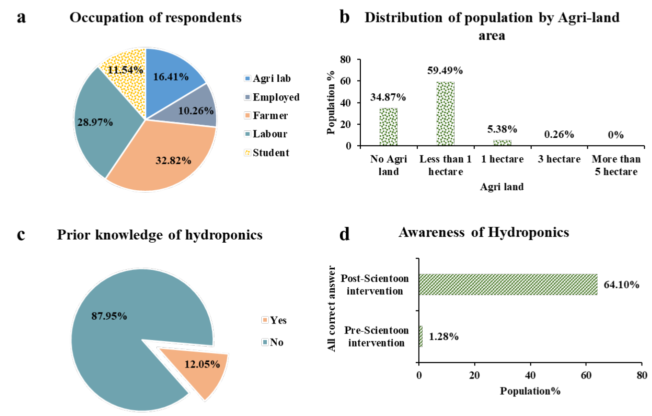


Fig. 3: Location of the study area: a. Map of India showing the position of Uttar Pradesh, b. Map of Uttar Pradesh indicating the location of Prayagraj district, c. Detailed map of Prayagraj district showing Phulpur tehsil and the study villages, with a color-coded legend indicating respective administrative boundaries

Sources and methods of data collection

Both primary and secondary sources were utilized to gather the data for the current study. A structured questionnaire containing 22 questions in both English and Hindi was used to gather quantitative data from the rural people. The questionnaire was divided into four sections, in the first section demographic profile of respondents was included. The second section included the questions to assess the respondents' own knowledge regarding hydroponic techniques pre-intervention of Scientoon. The third section includes the Scientoon-based comic for storytelling to spread awareness about hydroponics among respondents. In the fourth section, questions related to hydroponics post-intervention of Scientoon were included, along with the same questions asked in the second section to check their effectiveness in promoting hydroponics. The qualitative data were collected through some open-ended questions that gave a more detailed scenario of the villages. An in-depth survey was conducted in two parts, pre and post-intervention of Scientoon, by distributing the questionnaire among the villagers for data collection, and a semi-structured interview was used for one-on-one interaction with participants who were introduced to the Scientoon. The data was collected in the month of December 2024 in multiple sessions, and these sessions explored participants' comprehension and the perceived effectiveness of the Scientoon in conveying information about hydroponic techniques. The Census of India (2011), government reports, government websites, newspapers, and research papers were the sources of the secondary data.



Source: Author's own analysis derived from primary data.

Fig. 4: Respondents' distribution in the sample based on: a. Occupation, b. Agricultural landholding, c. Prior knowledge, d. Awareness about hydroponics

Sampling of Data

To choose the participants for the study, a random selection technique was employed. The questionnaire was distributed in 3 villages of the Bahadurpur block in Prayagraj district, and a total sample of 390 respondents was collected from all three villages. To get a more reliable measurement, only 130 respondents were selected from each village. The number of villages and samples may have been increased in the study, but doing so would have increased sample heterogeneity and made robust econometric modeling more challenging. Therefore, to ensure a sufficient size of sample, the intended degree of precision, the required level of confidence, and the probable proportion of the characteristic present in the population, Cochran's (1977) statistical method was utilized. It is the most commonly used formula for calculating the minimum size of a sample, particularly when the size of the population is very big, say greater than 50,000. The following modified Cochran's formula was used to determine the sample size (Fig. 3).

$$ss = \frac{z^2 * (p) * (q)}{e^2}$$

Where SS = required size of sample,
Z =Z-value matching the level of required confidence
p = p is the estimated percentage of an attribute that is present in the population
e = Margin of error (the level of precision)
q = (1-p)

Data analysis

The gathered data was first entered into the SPSS data file, labeled, and checked to determine whether any values were missing. The cleaned and processed data were then taken for analysis. Software such as SPSS and R Studio was used for data analysis. Various statistical methods were employed to analyze the collected survey data. The impact of Scientoon on creating awareness about hydroponic techniques among rural people was examined through various methods. Standard statistical measures, including arithmetic mean, frequency distribution, standard deviation, etc., were utilized to summarize the data. A regression model, such as the Probit model, designed for a binary limited dependent variable, was used to identify the influence of Scientoon with various social, economic, and demographic factors on awareness about hydroponic methods post-intervention of Scientoon, which was conducted through R Studio. Variables incorporated in the regression analysis are shown in Table 2. The probit model was estimated as follows

$$\Phi^{-1}(Y_i) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_k X_k + \mu_i$$

Here, $\Phi^{-1}(Y_i)$ represents the inverse of the standard normal distribution's cumulative distribution function (CDF), linking the probability of awareness Y_i to the dependent variable (linear predictor). Y_i is the probability that a person is aware of hydroponics. $\beta_0$is the intercept term, β_1 ,β_2....β_k are coefficients representing the impact of independent variables on the probability of awareness, X_1, X_2,...X_k are independent variables (predictors) and $\mu_i$is considered an independent, generally dispersed random disturbance term with a mean value of 0 and a variance of σ^2. In most of the cases, only prevalence may be observed, not the accurate Y_i (Gujarati and Porter, 2009). Therefore, the prevalence of awareness about hydroponic techniques was viewed from a rational choice perspective. The models were estimated using the maximum likelihood estimation (MLE) method.

Further, the partial correlation coefficients were computed between the different variables for a broader understanding of interdependence. To address the heteroscedasticity issue, the z-statistics in the probit model were calculated using White's (1980) heteroscedasticity-adjusted robust standard errors. The variance inflation factors (VIFs) and tolerance were computed to determine the degree of multicollinearity. Furthermore, to ascertain whether there was a lack of goodness-of-fit, the Pearson's x^2test and Hosmer-Lemeshow x^2 test were calculated in accordance with Mishra and Mishra (2017). The tests indicate that the model fitted well when the statistics are not significant. The impact of Scientoon in creating awareness about hydroponic techniques was also examined through the McNemar test (Lachenbruch, 2014), a non- parametric test to understand the exact difference in pre and post-intervention of Scientoon.

By combining these methodologies, the research aims to offer a detailed evaluation of how Scientoon influences the understanding of rural people, promoting willingness to adopt hydroponic techniques in farming. The adoption of technique depends on several other factors, explained in the conceptual framework.

Results

Descriptive Statistics

This portion of the paper examines how 390 respondents in three villages of the Bahadurpur block in the Prayagraj district of Uttar Pradesh have answered queries related to hydroponic techniques. Therefore, even though the information and data used in the paper were gathered from only 390 respondents, they nevertheless reflect the entire population of the

Table 2: Variables incorporated in the regression analysis: Key predictors and their probable effect in the model

S. No.	*Variables*	*Variable name*	*Description/Dimension*	*Probable Effect*
			Dependent Variables	
1.	Aware of hydroponics post-intervention of Scientoon	Aware_ hydro	Aware about hydroponics =1, if a respondent correctly answers all the questions related to the hydroponic technique, and 0 otherwise	
			Independent Variables	
1.	Gender	Gen	Gender of respondent = 1 for male, because they have active participation in agriculture, and 0 for female	Positive
2.	Age group	Age	Ordinary logarithm of age on awareness of hydroponics	Positive/ Negative
3.	Caste	Caste	Respondent caste = 1 for the person belong to the general category, and = 0 for others. For the regression study, the respondents are broadly classified into two groups only: the general category and the remaining others. The "remaining others" includes individuals from marginalised categories, such as, the Scheduled Castes, Scheduled Tribes, and Other Backward Class.	Positive/ Negative
4.	Educational qualification	Edu	Educated person = 1 if the education level is Secondary, Higher secondary or College/University, and = 0 for a person who were Illiterates or had education upto Primary level.	Positive
5.	Occupation	Occu	The occupation of a person has been divided into two groups = 1 for those engaged in Farming, Employed or Student, and = 0 for others, i.e., those who are engaged as Agriculture laborers and laborers outside agriculture, as they are considered as marginalised and poor	Positive/ Negative
6.	Agricultural land holdings	Agri_land	Ownership of agricultural land =1 if a person has agricultural land, and = 0 for otherwise	Positive
7.	Prior knowledge about hydroponics	Prior_ know_ hydro	Prior knowledge about hydroponics =1, if a respondent correctly answers at least two out of five or all the questions related to the hydroponic technique pre-intervention of Scientoon, and = 0 for other	Positive
8.	Role of Scientoon	Scientoon	Post viewing the Scientoon, if a respondent was interested in adopting hydroponics or sharing it with others =1, and =0 for not interested	Positive/ Negative

Bahadurpur block. Hence, the sample is quite comprehensive. Since these respondents reflect the awareness scenario in the area, the robustness of the models and the implications of the findings are not limited by the small sample size.

Supplementary Table 1presents the socio-economic profile of respondents participating in the survey on promoting hydroponics through Scientoon. The percentage of male respondents (58.72%) is more than female (41.28%), with most of them belonging to the age group of 26-45 years (51.28%), followed by more than 45 years (27.18%), and then less than 25 years (21.54%). The composition of other backward classes (OBCs) category is (49.23%) followed by the Scheduled Castes (SCs) (44.36%) and then the general caste (6.41%). Importantly, a sizable percentage of respondents (35.90%) are illiterate, while 15.13% up to primary level (those are also considered as illiterate for econometric modeling), 18.46% up to secondary level, 15.64% up to higher secondary level and 14.87% possess college or university level of education, indicating limited educational attainment.

Further, Fig. 4a shows that approximately 49.23% working population, including agricultural laborers, is directly or indirectly involved in agriculture, followed by non-agricultural laborers 28.97% and a smaller percentage 10.26% is employed in other sectors, while students constitute 11.54% of the total sample. Overall, 65.13% of the respondent owning agricultural land, but Fig. 4b shows that about 59.49% of the respondents have less than 1 hectare, 5.38% have 1 hectare and only 0.26% have 3 hectares of agricultural land, indicating the majority of them are small or marginal farmers. Additionally, it is noticed that the region's agricultural output varies greatly, which causes variability in household income. This underscores the need to promote "cost-effective", sustainable and transformative farming practices such as hydroponics (Fig. 4).

However, Fig. 4c and d indicate that although 12.05% of the respondents were aware of the term hydroponics, only 1.28% possessed a clear understanding of it. This indicates the need for Scientoon to improve awareness of hydroponics, resulting in better outreach and communication to promote sustainable agricultural practices.

Evaluating the impact of key variables on respondents' awareness of hydroponics

The variable's descriptive statistics included in the regression model are shown in Table 3 and partial correlation coefficients of awareness about hydroponics with explanatory variables are shown in Table 4. Additionally, the information on tolerance

Table 3: Descriptive statistics of variables used in regression analysis for assessing the impact of Scientoon on hydroponic awareness (sample size 390)

Variable	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Aware_hydro	0.641	0.480	0	1
Gen	0.587	0.493	0	1
Age	38.744	14.540	18	83
Caste	0.064	0.245	0	1
Edu	0.490	0.501	0	1
Occup	0.546	0.499	0	1
Agland	0.651	0.477	0	1
Prior_know_ hydro	0.121	0.326	0	1
Scientoon	0.756	0.430	0	1

Source: Author's own computation derived from primary data.

Table 4: Assessment of multicollinearity and strength of a linear relationship: Partial correlation coefficients with corresponding tolerance and Variance Inflation Factor (VIF) statistics

Independent variables	*Dependent variables*	*Collinearity statistics*	
	Aware_hydro	*Tolerance*	*Variance inflation factor*
Gen	0.131**	0.897	1.115
Age	-0.048	0.786	1.272
Caste	0.081	0.945	1.059
Edu	0.148**	0.681	1.468
Occup	0.090•	0.626	1.597
Agland	0.041	0.686	1.458
Prior_know_hydro	0.077	0.819	1.222
Scientoon	0.474***	0.937	1.067

Source: Author's own calculation resulting from primary data.
Note: Statistical significance levels are denoted as p < 0.05 (*), p < 0.01 (**), p < 0.001 (***)

and variance inflation factors (VIFs) is provided in Table 4. The threshold value of tolerance for detecting multicollinearity is generally reciprocal to the variance inflation factor (VIF) (Miles, 2014). Here, the tolerance (more than the threshold value of 0.1) and very low values of the variance inflation factors (far less than the threshold value of 10) suggest that multicollinearity is not a serious problem and are acceptable.

The findings of the estimated probit model are shown in Table 5. The statistical significance value of the Wald x^2 confirms the validity of the estimated models. Further, Pearson's x^2 test suggests the model fit is acceptable but close to the threshold of adequacy, but the Hosmer-Lemeshow x^2 test indicates that there is no issue with lack of goodness-of-fit in the estimated model (Table 6).

Table 5: Showing determinants of respondents' awareness and understanding of hydroponic techniques

Probit model		
Variable	*Coefficient*	*z-value*
Intercept	-1.390 ***	-4.261
Gen	0.373*	2.376
Age	-0.005	-0.932
Caste	0.589	1.589
Edu	0.480**	2.741
Occu	0.316 •	1.702
Agri_land	0.179	0.977
Prior_know_hydro	0.395	1.385
Scientoon	1.596***	8.612
[1]Wald x^2 (8)	66.3	
[2]Prob.>x^2	2.7e-11	
[3]Log Likelihood	-183.841	
[4]Pseudo- R^2	0.278	
Number of Observations	390	

Source: Own estimation using primary data.
Note: Statistical significance levels are denoted as p < 0.05 (*), p < 0.01 (**), p < 0.001 (***)

Table 6: Assessing the goodness of fit of the probit model

Model		
Probit model	*Pearson goodness of fit*	*Hosmer- lemeshow goodness of fit*
	Sample Size = 390	Sample Size = 390
	Quantity of covariate patterns = 259	Quantity of groups = 10
	Pearson x^2(381) = 425.074	Hosmer- Lemeshow x^2(8) = 6.572
	Prob.> x^2= 0.059	Prob.> x^2= 0.583

Source: Own computation using primary data.

In the probit model, it was found that the awareness of hydroponics (Aware_hydro) depends significantly on gender, education, occupation, and exposure to Scientoon (scientific cartoon). While the occupation of the respondent is marginally significant, it is positively associated with awareness. The variables like caste, agricultural landholding, and prior knowledge about hydroponics are positively associated, but their impact is not significant. The regression analysis further revealed a negative but not significant association between awareness of hydroponics and age suggests that although awareness of hydroponics tends to decrease slightly with increasing age of the respondents, the effect is not strong enough to rule out random variation.

Table 7: Comparison of respondents' awareness levels of hydroponics pre and post-intervention of Scientoon using the McNemar test

Awareness about hydroponics pre-V/S post- intervention of Scientoon				
		Aware_hydro post-intervention of Scientoon		
		0 (Not aware)	*1(Aware)*	*Total*
Aware_hydro pre-intervention of Scientoon	0 (Not aware)	124	219	343
	1 (Aware)	16	31	47
	Total	140	250	390
McNemar Test statistic				
		No. of valid case	390	
		Chi-Square[a]	173.634	
		Asymp. Sig.	0.001	

[a]Continuity Corrected

Non-parametric test results: evaluating the impact of Scientoon on respondents' awareness of hydroponics

To understand the clear change in level of awareness on hydroponic techniques pre and post-intervention of Scientoon, the McNemar test has been performed on paired nominal data. Table 7 demonstrates that not only out of 343 respondents who were initially not aware of hydroponics, 219 (63.84%) became aware post-intervention of Scientoon, but also among the 47 respondents who were initially aware, 31 (65.96%) maintained their awareness post-intervention of Scientoon. The McNemar test yielded a statistically significant result ($x^2 = 173.63, p < 0.001$) Table 7 indicating a meaningful positive change in awareness levels and willingness of respondents to adopt hydroponics post-intervention of Scientoon.

Discussion

The present study provides the first empirical evidence demonstrating the effectiveness of Scientoon (scientific cartoon) as an innovative visual communication tool for enhancing awareness of hydroponic farming techniques among the rural population in low-literacy settings. The findings of the sociodemographic determinants of awareness, together with the effects of the Scientoon-based intervention, as demonstrated through various statistical tests, indicate that visual communication strategies can effectively support technology adoption in resource-constrained rural areas.

The findings of the regression model demonstrate that the awareness of hydroponics and its adoption willingness are significantly influenced by determinants such as gender, education, occupation, and exposure to Scientoon. The awareness of the respondents about innovative farming practices, such as hydroponics, is significantly influenced by the male gender. The patriarchal influence of society may be the reason for this, as the sample included more male responses than female ones (Sultana, 2010). The findings of the study reveal that gender-based disparities in access to information and education may play a crucial role here because in villages, males often have better access to resources, education, agriculture extension services, training programs and scientific knowledge compared to their female counterparts, which supports the notion of Jost *et al.* (2016). The study also reveals that while male respondents are more aware of hydroponics than females, this difference requires further inspection to cognize the underlying socio-cultural factors and highlight the target interventions to bridge the gaps.

In the current study, although the age of the respondent is negatively associated with awareness and willingness of hydroponics adoption, its impact is statistically insignificant. This is possibly because respondents in the lower age group are more educated, but they are less interested in farming. Earlier studies also show that younger individuals tend to have higher educational attainments than older individuals, which may influence their awareness level of sustainable agricultural practices (Barro and Lee, 2013), but it does not guarantee their interest in farming. Educated individuals appear to have a higher likelihood of being aware of hydroponics because they easily understand the benefits of hydroponics, such as efficient use of water, low reliance on soil, and enhanced productivity in limited space, supporting the notion that education is essential for fostering knowledge of innovative agricultural practices. This aligns with the observations of Cerulli *et al.* (2020), who emphasized that education has inordinate potential to prominently raise awareness of environmental hazards and reduce their effect. In a similar way, Rohaeti and Nurhayati (2023) also highlighted that education plays a crucial role in the adoption of hydroponics and promoting environmentally sustainable behaviors because it provides farmers with the necessary knowledge and skills to transition from conventional agricultural practices to hydroponic techniques. Therefore, investing in education, especially in developing countries like India, is crucial for spreading awareness about innovative and sustainable agricultural practices (SAPs).

While occupation was marginally significant, its impact was positive on awareness and willingness to adopt, this is so possibly because it affects the affordability and accessibility of the resource (Asule *et al.*, 2024). Although not directly measured in this study, the perception of hydroponics as a costly and technologically advanced practice may limit its appeal to small and marginal farmers. Similar to the case of LPG cylinders, the cost associated with setting up hydroponic systems might act as a barrier, particularly for small and low-income farmers (Swain and Mishra, 2020). Variables such as caste and agricultural landholding show positive results; their impact is statistically insignificant. This might be because awareness about hydroponics, like innovative farming practices, is less influenced by traditional socio-economic factors or might reflect the homogeneity of the sample with respect to these variables. Similarly, prior knowledge about hydroponics is positively associated but not significant; this might be because such knowledge is likely limited or fragmented within the sample population.

Statistically significant and positive association of exposure to Scientoon with awareness of hydroponics demonstrates their effectiveness in communication and behavior change towards adoption, further supported by the results of the non-parametric McNemar test, as well as observations by Cohen *et al.* (2024), who highlighted the impact of visual aids in learning and behavior outcomes. This is possibly because exposure to information with the help of an innovative outreach tool like Scientoon appears to play an important role in the dissemination of complex scientific information in a visually engaging and relatable way, making the idea of hydroponics more accessible to diverse audiences. This study aligns with previous research findings, for instance, Srivastava et al. (2020), through the book "*Bye Bye Corona," effectively employed Scientoon to raise public awareness about the novel coronavirus*. Similarly, Shukla *et al.* (2025), to disseminate the information about the effect of heavy metal toxicity on the germination of wheat plants, have also used the Scientoon. In the same vein, Badeo and Koc (2021) recognize the role of Scientoon in science communication.

Although the study provides important insights into the use of Scientoon in promoting awareness of hydroponics, it has certain limitations. The study was purposively limited to three villages within a single block for more controlled implementation of the Scientoon-based intervention, to avoid heterogeneity and more reliable measurement of change in awareness before expanding to a larger region. Therefore, the finding may not be generalized beyond regions of similar socio-economic and agricultural contexts. The observed improvement in the level of awareness may be tentative and does not guarantee actual adoption because other factors, like the perception that hydroponics is costly, may still limit its adoption.

Conclusions

The study examines the reasons behind the limited adoption of hydroponic farming among rural households and identified lack of awareness as a major constraint. The application of Scientoon was done as a communication tool to fill this awareness gap, and findings demonstrate a statistically significant improvement as validated by both the probit model and the McNemar test. Demographic factors such as gender, education, and occupation shaped awareness outcomes and highlighted the need for targeted and equitable extension strategies. Importantly, the study underscores that Scientoon is a cost-effective and engaging visual communication tool for simplifying complex agricultural concepts. It can be effectively integrated into farmer training programs, awareness campaigns, digital outreach, and field demonstrations by agriculture extension agencies and policymakers for strengthening communication, improving comprehension among less literate populations, and supporting the dissemination of government policy and other sustainable agricultural practices, like hydroponics. The study also demonstrates that although the application of Scientoon improved awareness of hydroponics and helped in changing behavior, sustained efforts are needed to consolidate it in practical application. The findings of the study suggest that only awareness and willingness do not guarantee the adoption of the technique; broader educational initiatives and financial assistance to small and marginal farmers for the initial setup of hydroponic systems are essential.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The author confirms contribution to the paper as follows: Study Conception and design: Rohit Shukla, Pradeep Sahu; Anurag Koch and Anjali Hazarika; Data Collection: Rohit Shukla and Rohit Kumar Mishra; Interpretation of results: Nikita Sharma, Anupam Dikshit, and Vani Mishra; Draft Manuscript Preparation: Rohit Shukla, Anupam Dikshit, Vani Mishra and Rohit Kumar Mishra.

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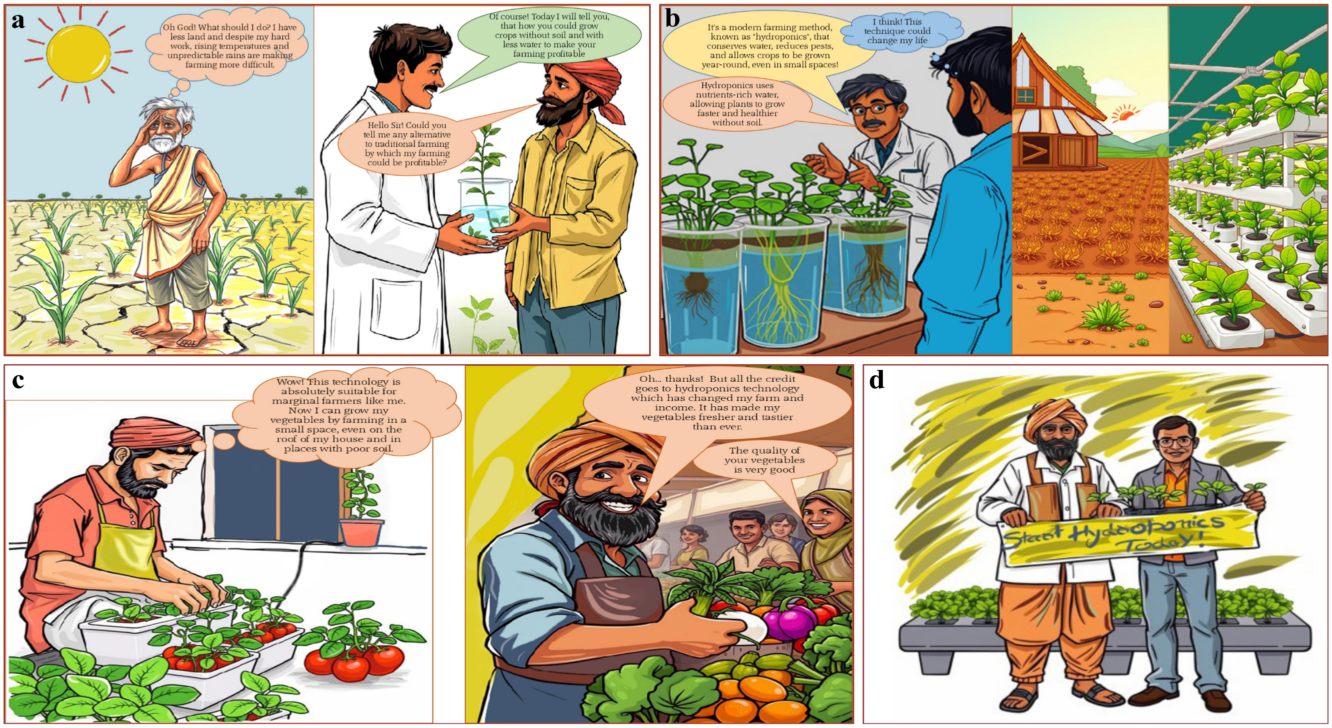
Supplementary



Supplementary Fig. 1: Pictorial depiction of Scientoon-based comic (a-d): used to disseminate awareness and willingness to adopt hydroponics among rural people towards sustainable agriculture practices (SAPs)

Supplementary Table 1: Basic profile of respondents participating in the survey on promoting hydroponics through Scientoon

Aspect		*Frequency*	*Percentage*
	Sociodemographic Profile		
Gender	Male	229	58.72
	Female	161	41.28
Age groups	25	84	21.54
	26–45	200	51.28
	>45	106	27.18
Caste	Gen	25	6.41
	OBC	192	49.23
	SC/ST	173	44.36
Educational qualification	Illiterate	140	35.90
	Primary	59	15.13
	Secondary	72	18.46
	Higher Secondary	61	15.64
	College /University	58	14.87
Occupation	Agri lab	64	16.41
	Employed	40	10.26
	Farmer	128	32.82
	Labour	113	28.97
	Student	45	11.54
Agriculture land	Yes	254	65.13
	No	136	34.87
Prior knowledge of hydroponics	Yes	47	12.05
	No	343	87.95

Source: Author's own analysis derived from primary data.
Note: 1. Education at the primary level and below is classified as illiterate in econometric modelling.
2. Both government and private employees are considered employed.