Vidyodaya Journal of Management
2023, Vol. 9 (I) **174 - 220**

ISSN 2448-9344 (Print) ISSN 2448-9352 (Online)
ISBN 978-955-23-0019-3
Reprints and permissions:
vjm@sjp.ac.lk
DOI: https://doi.org/10.31357/vjm.v9iI.6378

The Nexus between Agricultural Technology Adaptation and Productivity: Evidence from Hydro Greenhouse Systems in the Mullaitivu District

Gopikrishna Selvananthan
University of Sri Jayewardenepura, Sri Lanka

Sampath Amaratunge
University of Sri Jayewardenepura, Sri Lanka

Janaka Fernando
University of Sri Jayewardenepura, Sri Lanka

Ananda Rathnayake
University of Sri Jayewardenepura, Sri Lanka

Abstract

Sustainable technological innovation can resolve the economic crisis that exists within a nation. Sri Lanka is a developing country with one out of every six people suffering from multidimensional poverty (UNICEF, 2022). The research serves as an experimental approach to achieve the Sustainable Development Goals [SDG] of no poverty (SDG No. 1), decent employment and economic growth (SDG No. 8), and industry, innovation, and infrastructure (SDG No. 9). The study involves conducting an experimental survey in the Mullaitivu District, focusing on three agricultural households selected from three Grama Niladhari Divisions (GNDs). The selection of these households was done using a stratified simple random sampling technique, ensuring representative coverage of the district. The study conducted utilizes technologically sophisticated interventions, referred to as a hydro greenhouse. This encompasses a greenhouse that is furnished with a hydroponic system, along with the inclusion of a photosynthetically active radiation diode. The control and experimental setups were reviewed for a period of 90 days. In conclusion, technological intervention in agriculture across war-torn regions has resulted in a significant

Corresponding Author:
Gopikrishna Selvananthan, University of Sri Jayewardenepura, Sri Lanka. E-mail: gopikrishnaselvananthan@gmail.com

increase in productivity, reduction in cost, and effective land and water utilization. Productivity was determined based on plant height and fruit yield. The households were trained on the construction and management techniques of the prototype named hydro greenhouse[1]*. To facilitate the commercialization of this method, it was proposed that the GND and DS officers leverage the results of the conducted experiment to obtain financial support from both governmental and non-governmental organizations.*

Keywords: *Agricultural Technology, Greenhouse, Hydroponic System, Poverty Alleviation, Productivity*

Introduction

Sri Lanka, an island nation distinguished by its cultural diversity and remarkable natural landscapes, is an integral part of the global dynamics characterized by ceaseless evolution. Yet, an evident hesitation within the country to fully incorporate technological advancements could potentially destabilize its socio-economic equilibrium. Numerous factors shape Sri Lanka's socio-economic landscape. Notably, the long-standing consequences of an extended Civil War [2], coupled with the prevailing conditions in its aftermath, contribute significantly to the enduring poverty in the country. The reluctance to integrate technological developments in areas affected by the conflict intensifies the situation, giving rise to a digital divide that exacerbates socioeconomic disparities. The reluctance to adjust to technological transformations exerts a dual impact. On one hand, it constrains the economic potential of pivotal sectors like information technology, agriculture, and manufacturing, which could otherwise make considerable contributions to the country's gross domestic product. On the other hand, it contributes to social inequality, as marginalized communities, particularly those residing in post-conflict regions, are left in the periphery of the digital revolution, consequently deepening poverty and social inequity. In this context, the reticence to adopt technology not only hampers economic growth but also obstructs the healing and reconciliation process in

---

[1] The hydro greenhouse technique, developed by the author (Gopikrishna Selvananthan), combines greenhouse infrastructure, photosynthetically active radiation, and hydroponic systems to create an innovative growing method. This paper aims to comprehensively evaluate and analyse the hydro greenhouse technique, providing a detailed assessment of its components, features, and effectiveness.

[2] The Civil War that existed was between the Government Forces and the Liberation Tigers of Tamil Eelam. The Civil War started in 1983 and it took place in four main phases. The Eelam War I in 1983 which then led to the Eelam War II 1990-1994, Eelam War III 1995-2001, and the Eelam War IV 2006-2009.

post-conflict areas of Sri Lanka, thereby affecting the overall social equilibrium of the country.

The Civil War, which ravaged Sri Lanka for over three decades, had profound implications for the country's economic stability. The persistent conflict has affected domestic production across various sectors in different provinces, with the agriculture sector being one of the most affected (Food and Agriculture Organization [FAO], 2018). Since 2006, the Northern Province of Sri Lanka has experienced more than 10% of the country's overall poverty, which is bolstered by the highest vulnerability score of 18.4% for the propensity to fall below the poverty line by Mullaitivu District from 2019 till 2024 (Department of Census & Statistics [DCS], 2011; DCS, 2015; DCS, 2018; DCS, 2019; DCS, 2022). An examination of the agricultural practices employed by farming households in the Northern Province reveals a predominance of traditional/indigenous farming methods over modern techniques (DCS, 2018; DCS, 2019; DCS, 2022). This reliance on indigenous agricultural practices further emphasizes the technological divide and its implications for economic and social stability.

The Mullaitivu District shares similar behavioural, psychological, and geographical characteristics with the other four districts in the Northern Province. Following the preliminary survey conducted in the Northern Province, the Mullaitivu District was chosen for the experimental study. The households in the Mullaitivu District were observed with limited exposure to modern and sophisticated production techniques or technologies. As such, the primary objective of the study is to assess the impact of technological intervention on agricultural productivity. In the modern world, agriculture/cultivation entails many advanced techniques/technologies, as such the experimental study hereby focuses on the advanced techniques/technologies such as hydroponic systems inferred with nutrient film technique, greenhouse and externally supplied photosynthetically active radiation. During the experimental connotation stage, the farmers are provided with technical knowledge regarding advanced procedures employed, which contributes to the human capital growth of the farmers. Not only does the experiment endorse human capital development, but it also serves as a revenue generator, enhancing productivity and optimizing wealth within households, thereby reducing poverty in the region (Newhouse, Suarez Becerra, & Doan, 2016; Abeywardana *et al*., 2019).

The succeeding segments of this study are organized as follows: The literature review critically examines the subject of agricultural productivity, its correlation with agricultural innovation, and the theoretical foundation that supports these ideas. The methodology section presents a thorough elucidation of the technological intervention, encompassing its characteristics, arrangement, site, and resources utilized during its execution. Following the methodology, the data analysis section assesses agricultural productivity by utilizing primary observations from both the control and experimental groups. Subsequently, the paper delves into an extensive discussion and concludes by summarizing the study's findings along with the potential implications they may have.

Literature Review

The literature review predominantly concentrates on four primary domains of evaluation. The initial appraisal involves an examination of the scholarly works on Agricultural Productivity. Subsequently, the innovations associated with agriculture and productivity are assessed along with an extensive review of the experimental studies conducted in agriculture. Lastly, the theoretical framework is scrutinized.

Agricultural Productivity

Agriculture is crucial for economic development, with agricultural productivity being a key factor in industrialization and sustained growth (Murphy, Shleifer, & Vishny, 1989). Matsuyama's study shows that agricultural productivity is affected by various factors such as lack of technology, intermediary goods (seeds and planting material, fertilizers and pesticides, machinery and equipment, fuel, and energy), financial market imperfections, and trade barriers (Matsuyama, 1992). Additionally, Matsuyama's findings demonstrate a positive relationship between agricultural productivity and economic growth in open economies. Aggregate productivity measures the amount of output generated from a limited input in an economy or sector, with agricultural productivity being measured by the aggregate production function in a specific region (Beintema *et al*., 2000). Studies across Europe, Paraguay, and other South American countries show that advancements in technology have led to increases in agricultural productivity (Fulginiti & Perrin, 1997; Beintema *et al*., 2000). However, in regions such as Uruguay, slower adaptation to technology, particularly in the livestock sector, has resulted in decreased productivity. Studies suggest that technological development should align with regional resource endowments to create a favourable environment for agricultural productivity (Arnade,1998; Paiva & Gazel, 2004). Technological advancements have significantly revolutionized agricultural productivity. The implementation of precision agriculture, which includes refined and sustainable farming practices, has amplified productivity. This enhancement is achieved through the facilitation of accurate weather change predictions and the identification of potential crop diseases (FAO, 2017; FAO, 2018; Kim & Kim, 2016; Lv & Liu, 2019). Despite these points, there remains a consistent global inequality in establishing sustainability in agricultural productivity.

Agricultural Innovation & Productivity

The relationship between agricultural innovation and productivity has been a focal point of extensive scholarly exploration. Agricultural production, a geographically diverse operation reliant on varied technologies and evolving natural resources, is influenced by consumer preferences, environmental conditions, economic structures, and government policies, which affect the suitability of innovations (Lee, 2005; Makate, 2019). Adelaja (2003) suggests that local adaptive technologies, such as biotechnologies, can benefit the economy of a nation on a larger scale. Ghadim and Pannell (1999), explore the relationship between individual farmers' acceptance of new agricultural innovations and the development of industry. They suggest that trailing an innovation leads to skill improvement and better decision-making, which are crucial for industry development. However, the adoption of agricultural innovation is influenced by socio-demographic attributes. The study concludes with on-farm trials and experiments to analyse farmers' uncertainty regarding the profitability of long-term crops involving the adoption of new innovations. A study conducted by Dhrifi in 32 Sub-Saharan African countries from 1990 to 2011 showed that technological innovation is a key factor in agricultural productivity. The study concluded that agricultural productivity has contributed to a reduction in poverty at an average scale of 32%, with the direct impact being 0.98% and the indirect impact being 0.22%. The findings showed that a 1% change in technological innovation led to a poverty reduction of 0.18% (Dhrifi, 2013).

Klerkx, Aarts, and Leeuwis (2010) stress the importance of agricultural innovation as a key factor in understanding technological, economic, and institutional changes within the agricultural sector. Similarly, Sunding & Zilberman (2001) underscore the significant role of technology in influencing agricultural and industrial development over the past century. Furthermore, Zilberman *et al*., (1991) posit that agricultural innovation, intimately tied to human learning and capacity, serves as a transformative force in developing countries. Additionally, the study conducted by Jayne, Mather, and Mghenyi (2010) also highlights the importance of agricultural innovation in addressing the challenges of poverty reduction and rural development. The adoption of agricultural innovation can improve the livelihoods of smallholder farmers by increasing productivity and income, promoting food security, and enhancing market opportunities (Sayer & Cassman, 2013; Government UK, 2011). The study emphasizes the need for policies and programs that support the dissemination and adoption of agricultural innovation, particularly in developing countries where agriculture is a primary source of income and employment. Agricultural innovation is a key factor in addressing the challenges of food security, poverty reduction, and environmental sustainability.

Over the past several decades, technological progress has catalysed considerable enhancements in agricultural productivity (Fuglie & Rada, 2013). Precision farming, which leverages cutting-edge technologies such as drones, Global Positioning System (GPS), and Internet of Things (IoT) devices, has streamlined farm operations, thereby boosting productivity (Zhang & Kovacs, 2012). Artificial Intelligence (AI) has surfaced as a potent instrument for agricultural innovation, offering predictive capabilities for weather patterns, crop diseases, and yield, thus empowering farmers to make well-informed decisions (Kamilaris *et al*., 2017). Genetic engineering tool, such as Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), has been employed to modify crops for improved resilience and productivity, potentially instigating a revolution in agriculture, especially in areas grappling with climate change (Jaganathan *et al*., 2018). Sustainable farming practices, including organic farming and regenerative agriculture, have demonstrated a capacity to strike a balance between productivity and environmental well-being, mitigating climate change repercussions (Ponisio *et al*., 2015). However, the availability of these innovations and their impact on productivity are subject to considerable variation. Socio-economic elements, governmental policies, and infrastructure play a pivotal role in the adoption and efficacy of these technologies (Sunding & Zilberman, 2001).

In conclusion, agricultural productivity continues to be driven by ongoing innovation, with a heightened emphasis on sustainability and resilience in the face of global challenges.

Review of Key Experimental Studies in Agriculture

Various experimental methods exist in agricultural research. The Splawa-Neyman, Dabrowska, & Speed approach uses a randomized field design based on a URN model (Splawa-Neyman *et al*., 1990). A study backed by IIASA and

UNEP investigated climatic variability's impact on agriculture using two primary experimental approaches: the Impact and Adjustment experiments, examining direct and indirect effects while exploring potential farm and governmental level adjustments (Parry & Carter, 1989). Yang (2010) demonstrated that the mixed-effect model with the SAS system's PROC MIXED can enhance data interpretation accuracy in crop research, despite the software's high costs. Vance (2000) utilized a randomized field experiment design to examine agricultural site productivity over the long term, introducing site productivity principles that stress the importance of soil organic matter, soil texture, and nutrient management for maintaining crop productivity. Besag and Higdon (2002) argued that Bayesian analysis, including Markov and Monte Carlo methods, can simplify the interpretation of results from agricultural experiments.

Bennett and Birol (2010) highlighted the utility of choice experiments in addressing agricultural and environmental issues in developing countries, valuing various interventions. Butler and Cornaggia (2011) found that access to external finance can significantly enhance agricultural productivity, as demonstrated by a natural experiment approach. Parker, Ramdas, and Savva (2016) conducted an experimental study using a natural experiment to evaluate mobile phone networks' impact on improving agricultural market efficiency. They found that timely access to accurate information through ICTs can enhance market efficiency, while a lack of such access decreases efficiency. In a separate quasi-experimental study, Javed, Haider, and Nawaz (2020) investigated how climate change influences agricultural practices aimed at managing market risk. Surveying 400 farming households in Pakistan, the study revealed that climate change affects adaptation strategies such as sowing date changes, crop diversification, and fertilizer use, also affecting market factors such as new opportunities and profitability. In conclusion, the integration of technology, innovative practices, and adaptive strategies are pivotal in optimizing agricultural productivity and market efficiency, thereby enhancing resilience and profitability in the agricultural sector.

Theoretical Framework

The author implements an empirical approach to scrutinize technological advancement by leveraging novel modelling methods and the principles of complexity science. The study predominantly assesses a triad of integral theoretical frameworks, encompassing the resource-based view (RBV), the diffusion of innovation paradigm, and the technology adoption model (TAM).

The Resource-Based View (RBV) posits that a firm's resources and capabilities are critical determinants of strategic actions and performance. Unique resources and capabilities can provide a competitive advantage, resulting in improved financial outcomes. Penrose (1959) first introduced RBV, asserting that growth is limited by available resources and managerial processes. Wernerfelt (1984) expanded RBV by introducing "resource heterogeneity" and "resource immobility," emphasizing the varying nature and non-transferability of resources and capabilities. Barney (1991) further refined RBV, highlighting the importance of organization-specific resources and capabilities in creating sustainable competitive advantages. In essence, RBV assists firms in developing differentiating strategies by leveraging unique resources and capabilities, promoting lasting success.

The Diffusion of Innovation Theory, introduced by sociologist Everett Rogers in 1962, is a framework explaining the spread of new ideas, products, and technologies among individuals or groups (Rogers, 1962). It highlights communication and social networks' role in innovation adoption and diffusion. Rogers proposed five stages of adoption: knowledge, persuasion, decision, implementation, and confirmation. Roger identified five influencing factors: relative advantage, compatibility, complexity, trialability, and observability. This theory, applied across various fields like business, healthcare, agriculture, and education, helps explain and predict technology and innovation adoption and design - effective communication strategies and policies for promoting diffusion.

The Technology Acceptance Model (TAM) is a prominent theoretical framework that elucidates the user acceptance of novel technology (Davis, 1986). It postulates that acceptance primarily hinges on two factors: perceived usefulness and perceived ease of use (Marangunic & Granic, 2015; Holden & Karsh, 2010). The term "perceived usefulness" refers to an individual's conviction that the utilization of a particular technology will augment job performance or productivity. In contrast, "perceived ease of use" pertains to the belief that the use of the technology will be devoid of effort. The TAM has found application in a diverse range of technologies, including but not limited to Information Systems, E-Commerce, Mobile Technologies, Educational Technologies, Healthcare Technologies, Agricultural Technologies, and Social Media; Further, it has demonstrated its worth in forecasting and elucidating technology adoption behaviour across an array of contexts (King & He, 2006; Lederer *et al*., 2000; Marangunic & Granic, 2015; Holden & Karsh, 2010; Li *et al*., 2019; Rose *et al*, 2018).

Experimental Methodology

Upon what foundation is the research premised?

The study conducted is a quantitative survey employing an experimental approach to evaluate the impact of technological interventions on productivity. The experiment took place in the Mullaitivu District in Northern Province, an area affected by civil war and marked by ongoing impoverishment (DCS, 2011; DCS 2015; DCS, 2018; DCS, 2019; DCS, 2022). Over 62% of Mullaitivu's households depend on agriculture and animal husbandry for sustenance (DCS, 2019; DCS 2022). Approximately 11.12% of the land is allocated to agriculture, while an estimated 63.18% is covered by dense and open forest, leaving 5.97% of the territory underutilized as non-agricultural, scrub, grass, non-forested marsh, and barren land (Chief Secretary's Secretariat – Northern Province [CSSNP], 2017; CSSNP, 2018; CSSNP, 2019; CSSNP, 2020). As mentioned earlier, nearly 70% of the land in Mullaitivu is ineffectively managed.

The Mullaitivu District is composed of six Divisional Secretary's [DS] Divisions, each demonstrating similar climatic conditions, soil compositions, and shared physiological and behavioural traits among the households. The authors conducted a preliminary analysis on 50 households from each of the DS Divisions, culminating in a total sample of 300 households within the Mullaitivu District. This preliminary exploration discerned a commonality of four shared characteristics namely - behavioural, psychological, and geographical - among the households in all six DS Divisions.

The research design employed a stratified simple random sampling method to determine the sample group for the study. In line with this technique, the Thunukai DS division, which mirrors the other divisions in terms of psychological, behavioural, and geographical characteristics, was selected. Subsequently, three households from Thunukai DS were chosen using the stratified simple random sampling method. These households, drawn from three Grama Niladhari Divisions (GNDs) namely Mallavi, Yogapuram East, and Kalvilan, represent the three identified strata. This approach thus ensures the selected sample embodies the broader spectrum of psychological, behavioural, and geographical characteristics within the Mullaitivu District. This study adheres to a pragmatic philosophical approach and embraces a positivist paradigm. Deductive reasoning was employed to corroborate the theoretical underpinnings of the researcher.

To assess the agricultural productivity of farming households in response to varying degrees of technological intervention, the study employs the randomized control trial methodology, as illustrated in *Figure 1*. Utilizing the single difference method approach, the investigation concludes that the selected households in the Mullaitivu District, Northern Province, exhibit higher agricultural productivity throughout the sample period when compared to the control group households, which received no technological intervention.

The randomized controlled trial formed two principal groups: a control group without technological intervention and an experimental group/treatment group implementing technological intervention. Each household in the sample group, chosen through stratified simple random sampling, underwent training on the technological intervention (hydro greenhouse system detailed in the subsequent paper). Every household possessed both control and experimental setup. The single difference approach was applied to document and analyse the disparities in productivity between the treatment and control groups across three phases of the growth cycle.

Upon identifying the households within the aforementioned strata, certain prerequisites were established for sampling these households. These included: the requirement for adequate space to accommodate both the treatment and control group structures; the presence of at least one family member in the household for the duration of the experiment (up to a maximum of 90 days); and the possession of a smartphone by at least one household member. The latter criterion was necessary to ensure effective communication between the researcher and the household members, given the considerable geographical distance between the researcher's location and the site of the experiment.

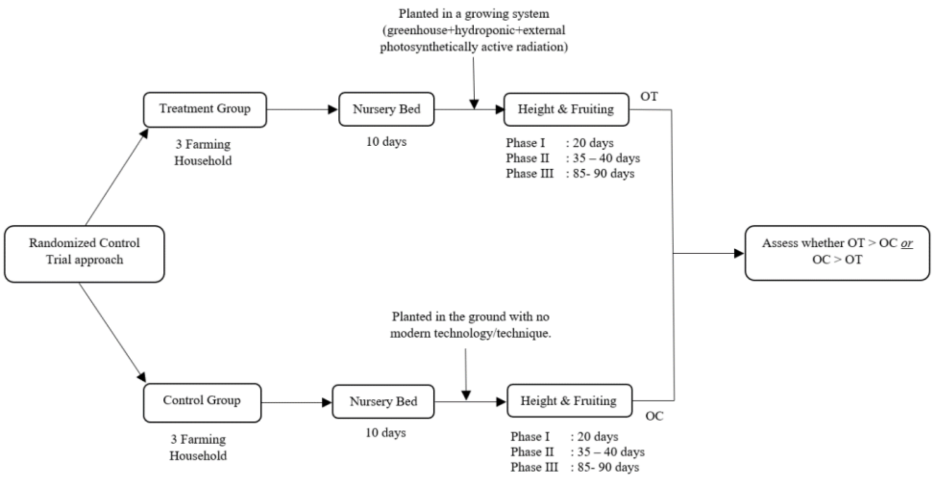

Figure 1. Randomized Control Trial Framework
Source: (Author,2022)

Note 1: *OT* refers to the Output of the Treatment Group and *OC* refers to the output of the Control Group

What resources were utilized in this study?

The technological intervention designed to be tested in Mullaitivu households is a hydroponic system equipped with photosynthetically active radiation and housed within a low-cost greenhouse. The application of technology was budgeted at the absolute lowest possible cost, considering household affordability *(The cost-benefit assessment is provided under the analysis section of the paper).* Throughout the procedure, the following materials/equipment were used.

Greenhouse

A greenhouse is a protective structure that protects plants from climate variations as well as external incursions and harm caused by animals and insects. Additionally, the existence of a greenhouse allows the plants to be heated by a variety of radiations, including short-wave radiation from the sun, infrared radiation from the ground that is concealed by the greenhouse, long-wave radiation from the atmosphere, and short-wave heat from the ground (Von Zabeltitz, 2011). Gable, flat arch, tunnel, dome, sawtooth, skillion, uneven, ridge & furrow, lean-to, tripenta, gothic, and A-frame are the twelve basic forms of greenhouses. The greenhouse's application varies based on the purpose and variety of the crops (Von Zabeltitz, 2011; Ponce *et al.*, 2014). The experiment hereby focuses mainly on the cultivation of chillies, whereas the temperature and humidity are key significant factors to enhance the chilli growth. The greenhouse technique that is used by the author is an *uneven greenhouse*.

The key raw materials that are used for the construction of a unit of the greenhouse are,

Table 1: Raw material breakdown of the greenhouse

Name	No. Units	Scale/per unit	Purpose
Greenhouse polythene (UV polythene)	01	5-metre length and 2-metre width	Protection from the short UV/IR wave and the long UV/IR wavelength from the atmosphere.
Wooden plank	02	1.2-metre length, 0.05-metre width and 0.02-metre height	To provide stiffness to the structure, particularly the roof. It also aids in tying the UV polythene to the structure being constructed.
PVC pipes	04	2-metre (¾ inch)	To create the height for the detached greenhouse skeleton (*Uneven greenhouse*)
	02	0.6-metre (¾ inch)	Create the width of the greenhouse.
Elbow joint PVC	04	90-degree joint (¾ inch)	Connect the 2-metre pipe to the 0.6-metre pipe.
Plastic buckets	04	0.15-metre height & 4-litre capacity	To make the PVC pipes upright in the ground after being filled with a cement and sand combination.
Cement	01	3 Kg	Fill the plastic bucket with concrete.
Sand	01	3 Kg	Fill the plastic bucket with concrete.
Jute Twine	04	1-metre	Connect the cross-dimensional structure to add stiffness to the framework.

Source: (Author, 2022)

The basic structure of the greenhouse skeleton is provided below. The greenhouse structure is consistent across all households under the experiment in order to minimize any bias/influence created by the construction toward productivity.

Figure 2. Greenhouse construction Step 01

Source: (Author, 2022)

Note 02: Initially the greenhouse skeleton is made at a height of 2-metre and breadth of 1.2-metre and the width of 0.6-metre.

Figure 3. Greenhouse construction Step 02

Source: (Author, 2022)

Note 03: Upon the successful completion of the skeleton the UV polyethene was fixed over the greenhouse skeleton that was built. The internal area available to place the hydroponic system is 1 m^2.

Hydroponic system

The hydroponic system is a modern breeding technique in which the plants are cultivated in the nutrient solution with or without an inert medium such as gravel, vermiculite, rockwool, peat moss, saw dust, coir dust, coconut fibre, etc. (Sharma *et al*., 2018). In comparison with soil-based cultivation, the hydroponic system conserves 90% of water, and 85% of fertilizer and enhances productivity by 250% (AlShrouf, 2017). Sharma *et al*. (2018) and Trejo-Tellez & Gomez-Merino (2012) say that hydroponic system can take up different forms namely, wick, drip, ebb flow, deep water culture, and nutrient film (NFT) techniques depending on the structure, purpose, nutrient supply, and other environmental limitations. The experimental setup carried out by the author uses Nutrient Film Technique (NFT) in the hydroponic system developed. The NFT circulates nutrient solution throughout the system, while the roots that are immersed in the flowing current absorb nutrients from the solution pumped from the reservoir.

The use of the Nutrient film technique in a hydroponic system can save up to 70% of the irrigation water. Furthermore, the findings imply that the application of the hydroponic system not only serves the farmer to earn greater yield in a shorter time period but also helps the farmers to cultivate crops in a waterless environment. The Albert solution is used to supply nutrient solutions in the form of inorganic ions to the system developed. The electrical conductivity of the solution is maintained at 1.8-2.0 dS m^{-1} while the pH is maintained at 5.7-.6.2 (Trejo-Tellez & Gomez-Merino, 2012; Sharma *et al.*, 2018; Son, *et.al.*, 2020). Under the experiment conducted, the hydroponic system primarily concentrates on the cultivation of the MI-2 chilli variety. The raw materials utilized in the construction of a hydroponic system are as follows:

Table 2: Raw material breakdown of the hydroponic system

Name	No. Units	Scale/per unit	Purpose
Plastic barrel	02	Sky blue colour with a height of 0.5-metre	One barrel serves as a reservoir, while the other serves as a medium for the plants to grow and the solution to circulate.
PVC pipes	01	0.5-metre (½ inch)	To eject the nutrient solution from the reservoir (lower barrel).
	01	0.35-metre (½ inch)	To expel the nutrient solution from the upper barrel to the lower barrel.
	01	0.5 metre (½ inch)	To connect the reservoir to the top barrel
	01	0.25-metre (½ inch)	To connect the reservoir to the top barrel's expel unit.
	01	0.3-metre (½ inch)	This aids in connecting the motor to the surface of the reservoir (lower barrel).
Elbow joint PVC	02	90-degree joint (½ inch)	To connect the PVC pipes from the expel and injection units to the appropriate flowing unit.
PVC Socket	07	½ inch	Connect the PVC pipes to the upper and lower barrels (reservoir), as well as the submersible pump to the injection unit.

S-Lon Solvent Cement	02	25 grams	Sockets and elbows are used to connect the PVC pipes.
Submersible pump	01	Voltage: 220V-240V50Hz Power: 50W F. Max: 2900L/h H. Max:3m	Used to pump the solution from the reservoir into the upper barrel holding the plant.
Net-pot	01	Upper diameter 0.55-metre and lower diameter 0.4-metre.	To place the chilli plant into the hydroponic system.
Albert Solution	04	200 grams	Albert solution consists of inorganic ions that are dissolved in the water to make a nutrient solution.
GroLine Hydroponic Waterproof pH/EC/TDC/Temperature portable meter, Digital Weighing Scale	01	Measurement should be scaled in the below range, $5.5<pH<6.5$ $1.5\ dS\ m^{-1}<EC<2.2\ dS\ m^{-1}$	Ms. Thushyanthy Ganeshkumar, an Agricultural Officer from Nelliady, Jaffna, offered the device for the experiment.

Source: (Author, 2022)

Skeleton formation of hydroponic system

1. Upper plastic barrel was injected with four holes and fitted with 4 PVC ½ inch sockets to link the system with the injection units. The upper three holes in the unit are mostly used to keep the water level stable as the plant roots grow. The growth statistics were obtained from the root growth observed from the demo run conducted in the control study from the period of 01st March 2022 to 30th May 2022. Each hole is set at a 05-centimetre distance from each other. (As per the previous observation the root growth in the 20 days was 05cm and 30-40 days are 10-15cm and 80-90 days are 15-20cm. The final hole at the bottom of the barrel is used to evacuate the nutrient solution from the system and back into the reservoir. The nutritional solution is ejected at a rate of 0.3 litres per second.

Figure 4. Upper Barrel with the outlets for injection and expel
Source: (Author, 2022)

Figure 5. Lower Barrel (reservoir) with the submissible motor along with the expel unit.
Source: (Author, 2022)

2. The picture depicts the lower reservoir, which is outfitted with a motor to pump water from the lower unit to the upper unit. The Albert solution is mixed with water in the reservoir barrel (lower barrel). The water level is kept at a height of 0.3-metre. The submersible pump is installed in the reservoir's basement and pumps the nutrient solution from the reservoir to the upper barrel at a rate of 0.8 litres per second. The motor operates at a voltage of 220V-240V, 50Hz, a power of 50W, an F.Max of 2900L/h, and a height of 3m.

Figure 6. The reservoir with the air aperture.
Source: (Author, 2022)

3. The illustration shows the lower barrel fitted with PVC sockets to link the injection unit and the expel unit to the higher barrel. Aside from the PVC socket, the reservoir (bottom barrel) has an air aperture (1 inch radius) to allow enough air circulation into the reservoir.

Figure 7. The upper unit fitted with the net pot.
Source: (Author, 2022)

4. The upper barrel is fitted with a net pot containing a chilli. The net pot is cushioned with inert media, specifically coconut husk and tiny gravels. The net pot has an average radius of one inch. Moreover, the previously mentioned greenhouse structure has the capacity to support up to four upper barrels concurrently.

Figure 8. Illustration on the flow of nutrient solution into the Ponic system.
Source: (Author, 2022)

5. Illustration provided gives a clear view on the nutrient solution level that flows into the top barrel of the Ponic system. The water is maintained in the upper system at a height of 0.35-metre. The upper system in the Hydroponic system is maintained at an elevation of 0.6-metre from the ground. The nutrient solution is being made by mixing the albert solution into the water in the reservoir. The maximum capacity of water in the reservoir is 5 litres. A minimum of 10 gram and a maximum of 20 gram of albert solution are mixed into the water. The nutrient solution in the reservoir is replenished every two days.

Figure 9. Completed hydroponic system.
Source: (Author, 2022)

6. The figure depicts the completed hydroponic system. A comparable system is duplicated in all three experimental locations, namely Kalvilan, Malavi, and Yogapuram East.

Photosynthetically active radiation

Photosynthetically active radiation (PAR) represents a crucial portion of the electromagnetic radiation spectrum that is absorbed by green plants to drive the process of photosynthesis (Mottus *et al*., 2013). Generally, the spectral range of this radiation lies between 400 and 700 nm. The presence of PAR stimulates photosynthesis, which subsequently promotes both plant growth and fruiting.

In the context of the experimental treatment unit, a PAR spectrum with a wavelength range of 650-720 nm was provided (Crawford *et al*., 2019). This specific wavelength range has been demonstrated to be particularly effective in enhancing the photosynthetic efficiency of plants, thereby optimizing their growth and productivity. The implementation of this tailored PAR spectrum in the experimental setup aimed to investigate the potential benefits of targeted light conditions on the growth and yield of plants, particularly within hydroponic systems.

By exploring the impact of a customized PAR spectrum on plant growth and productivity, it is optimum to develop a deeper understanding of the relationship between light quality and photosynthetic efficiency. This knowledge may then be applied to optimize growing conditions for a variety of crops, potentially leading to improvements in agricultural productivity and sustainability.

Table 3: Detailed Breakdown of the Photosynthetically Active radiation diode

Name	No. Units	Scale/per unit	Purpose
Photosynthetically Active Radiation Diode	01	The spectrum range is 650-720 nm	In order to provide the necessary electromagnetic radiation for plant growth, a 10W radiation diode was procured from China.

Source: (Author, 2022)

Figure 10. Photosynthetically Active Radiation Diode
Step 01
Source: (Author, 2022)

Note 4: The diagram illustrates the sample of the photosynthetically active radiation diode with the spectrum length of 650-720nm.

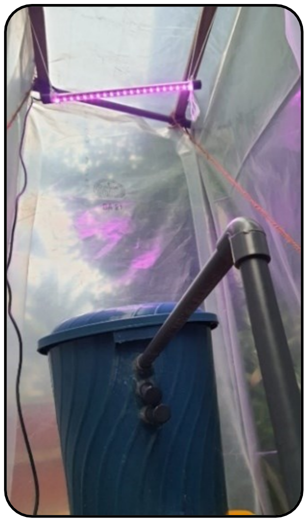

Figure 11. Photosynthetically Active Radiation Diode
Step 02
Source: (Author, 2022)

Note 5: Photosynthetically active radiation diode is being fixed within the greenhouse and the plants are being exposed to 02 hours to 04 hours daily in

Which plant species was utilized in the experiment?

The experiment used the MI-2 type of chilli. MI-2 chilli plants are a popular variety of chillies known for their unique characteristics, such as high heat resistance level, compact size, and early maturity. These plants require adequate sunlight, water, and nutrient-rich soil to thrive. The use of hydroponic systems and photosynthetically active radiation has been shown to enhance the growth and yield of MI-2 chilli plants significantly (Ghosh *et al*., 2020). The study findings hereby say that greenhouse farming utilizing hydroponic systems and photosynthetically active radiation has emerged as a promising approach to enhance the productivity and profitability of MI-2 chilli plants. This technique involves growing plants in a controlled environment where temperature, humidity, light, and nutrients can be precisely controlled to meet the optimal requirements of the plants. Hydroponic systems facilitate the cultivation of MI-2 chilli plants without soil, which eliminates the risks of soil-borne diseases, weeds, and pests. Hydroponic systems offer several advantages, including efficient water usage, reduced use of pesticides, and higher crop yields. Photosynthetically active radiation, or PAR, refers to the type of light that plants use for photosynthesis. By optimizing the light conditions in the greenhouse, the growth and yield of MI-2 chilli plants can be significantly increased. PAR lighting has been shown to increase the plant's metabolic rate, which results in faster growth, increased yields, and higher-quality produce.

In conclusion, MI-2 chilli plants are a popular variety of chillies that can benefit significantly from greenhouse farming, hydroponic systems, and photosynthetically active radiation. Application of the techniques discussed under the methodology, the growth and yield of MI-2 chilli plants can be optimized, leading to increased productivity and profitability for farmers.

How were the data recorded?

In concurrence with Wortman (2015), electrical conductivity refers to the capacity of an aqueous solution to conduct electrical current. This current is transported by ions, and the solution's conductivity is influenced by factors such as ion concentration, ion mobility, and water temperature. To measure electrical conductivity and pH concentration in the nutrient solution, the author utilized the GroLine hydroponic waterproof pH/EC/TDC/Temperature portable meter. The electrical conductivity of the solution was maintained within a range of 1.8-2.0 dS m-1, while the pH was kept between 5.7 and 6.2.

The temperature and the humidity of the environment are recorded continuously both inside and outside the greenhouse system. The temperature at Thunukai DS, Mullaitivu ranged from 28°C to 34°C, and the humidity ranged from 18°C to 24°C. The temperature within the greenhouse ranged from 30°C to 36°C, while the humidity ranged from 20°C to 26°C. The temperature and humidity were measured using the UNI-T Thermometer and Humidity Meter / Hygrometer UT333 respectively.

The productivity of the crops was gauged based on growth characteristics, particularly plant height and fruit yield. Growth observations were made at three distinct intervals: at the completion of 20 days, between 35-40 days, and between 85-90 days. A yardstick was utilized to measure plant height, from the ground level to the apex of the tallest stem, excluding leaves. Given the small sample size in both the treatment and control groups, fruit production was manually recorded. Fruiting commenced on the 60^{th} day, with recordings made between the 85^{th} to 90^{th} days. Furthermore, the weights of the fruits were measured using a digital weighing scale.

Techniques/Methods Significant for the Research

I. EC/pH

When the pH of the solution exceeds the buffer threshold of 6.2, 1 gram of crushed and dried corn kernels was added to the reservoir. The dried corn kernels are rich in carbon dioxide, dried corn kernels produce acid reacting with water solutions that lower the pH (Laria, Meza, & Pena, 2007). If the pH drops below the buffer level of 5.7, 0.1 grams of baking soda is added to the solution, as a result, the solution's alkalinity rises (Hara & Turssi, 2017).

II. Plastic Barrel

The plastic barrel is made of polymers that have a high likelihood of reacting with the nutrient solution, the plastic barrels (06 in number) for all three households were initially made with small holes and then fitted with sockets before being filled with silicone gel to seal the air opening to avoid water leakages. Following that, the plastic barrels were filled with clay and exposed to sunshine for a minimum of 24 hours. The chemical reactions of the polymer can be neutralized by clay (Lee *et al*., 2007). Additionally, it was observed that the experimental greenhouse setup had the capacity to hold up to four upper barrels and a single reservoir. However, to assess the reliability of the setup, a hydroponic system comprising a single upper barrel and one reservoir was installed in the greenhouse structure.

Findings

This section delves into the process of data analysis, scrutinizing the results garnered from the quantitative survey carried out to appraise the influence of the technological innovation referred to as the hydro greenhouse on agricultural productivity in the Mullaitivu District of the Northern Province. It also evaluates the cost-benefit implications of this technological intervention, culminating with an examination of the strategic significance of such an intervention. The study utilized an experimental approach to investigate the potential of these interventions to alleviate poverty in a region marked by post-civil war impoverishment and significant dependence on agriculture and animal husbandry. The findings of the study suggest that technological interventions can play a crucial role in poverty alleviation in the Mullaitivu District. By improving agricultural productivity, these interventions can increase farmers' income, improve food security, and reduce their reliance on external aid. Moreover, the study highlights the need for policymakers and development practitioners to prioritize the adoption of such interventions in impoverished regions.

Findings from Experimental Study Conducted in Mallavi GND

Upon analysing the experimental results obtained from the Mallavi GND, Thunukai DS, it became evident that the temperature and humidity conditions in Mallavi GND varied within the range of 28°C to 34°C and 20°C to 24°C, respectively. The control experiment conducted in the Mallavi GND of Mullaitivu District showed that the optimum plant heights observed were 6 cm in Phase I, 14 cm in Phase II, 22 cm in Phase III, and 35 cm in Phase IV. Similarly, the plants cultivated in the experimental trial, which was conducted in a greenhouse with a hydroponic system and photosynthetically active radiation, demonstrated an optimum height of 6 cm in Phase I, 16 cm in Phase II, 31 cm in Phase III, and 45 cm in Phase IV. Additionally, fruiting was observed during Phase IV of the growth cycle. In the control trial, three fruits were observed, collectively weighing 80 grams. In the experimental trial, on the other hand, seven fruits were observed with a combined weight of 204 grams.

A comparative analysis of the control and experimental trials showed that the plants cultivated in the experimental trial exhibited significantly faster growth rates. Both the control and experimental trials were initiated on the same day, with Phase I being planted simultaneously. It is worth noting that the descriptive analysis of the control and experimental trials conducted in households from Mallavi, Mullaitivu, presents a comprehensive understanding of plant growth under various conditions.

In conclusion, the experimental analysis conducted on the Mallavi GND, Thunukai DS provides valuable insights into the optimum growth conditions of plants under different scenarios. The findings indicate that a controlled environment, such as a greenhouse with a hydroponic system and photosynthetically active radiation, can promote faster growth rates and higher yields compared to natural conditions. This research has the potential to contribute significantly to the agricultural sector by improving plant growth and production efficiency. Refer to *Annexure 1* for a detailed productivity breakdown.

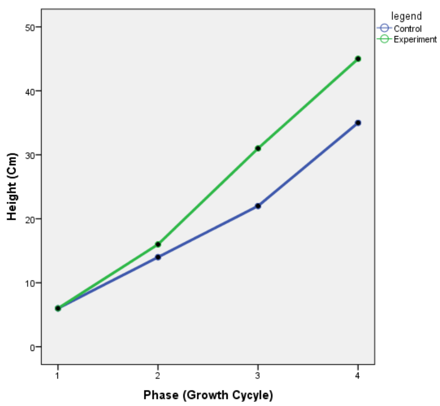

Figure 12. Height Comparison in between control and Experimental trials, Mallavi, Mullaitivu
Source: (Author,2022)

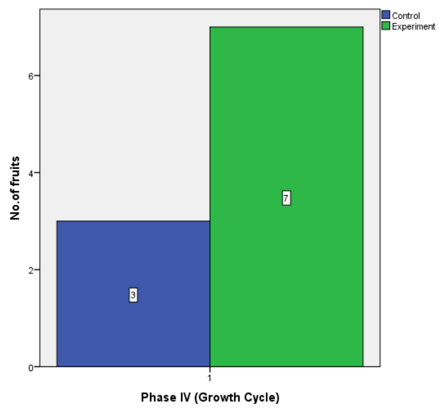

Figure 13. Fruiting Comparison in between control and Experimental trials, Mallavi, Mullaitivu
Source: (Author,2022)

Note 6: The graph denotes green colour for the experimental output and blue colour for the control output.

Findings from Experimental Study Conducted in Yogapuram East GND

After analyzing the study findings for the household located in Yogapuram East, the following conclusions were reached. The temperature and humidity levels in the vicinity of Yogapuram East were observed to fluctuate between 28°C to 34°C and 21°C to 23°C, respectively. During the control trial, the maximum plant height observed in Phase I was 5.5 cm, while Phase II exhibited a maximum height of 14 cm, Phase III had 22 cm, and Phase IV had 30 cm. Similarly, the maximum plant heights observed in the experimental trial were 5 cm in Phase I, 19 cm in Phase II, 32 cm in Phase III, and 40 cm in Phase IV. During Phase IV of the growth cycle, fruiting was observed, resulting in a yield of four fruits weighing 85 grams in the control trial. Conversely, the experimental trial produced six fruits with a combined weight of 200 grams.

The study findings from the household located in Yogapuram East provide valuable insights into the optimum growth conditions of plants under natural and controlled environments. The results indicate that a controlled environment, such as the one used in the experimental trial, can promote higher yields and faster growth rates compared to the natural conditions of the control trial. This research can contribute significantly to the agricultural sector by improving plant growth and production efficiency. To obtain a comprehensive breakdown of productivity in both the experimental and control groups, refer to *Annexure 2*.

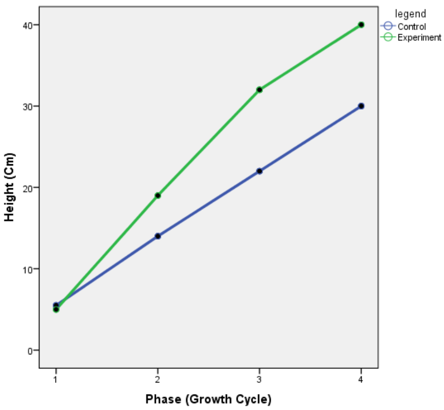

Figure 14. Height Comparison in between control and Experimental trials, Yogapuram East, Mullaitivu

Source: (Author,2022)

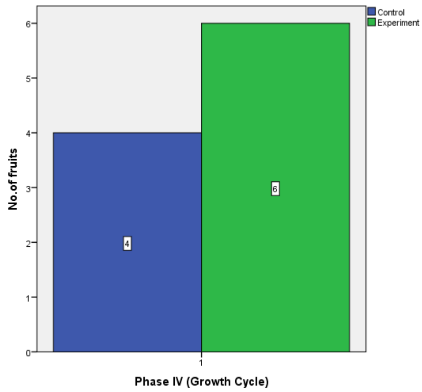

Figure 15. Fruiting Comparison in between control and Experimental trials, Yogapuram East, Mullaitivu

Source: (Author,2022)

Note 7: The graph denotes green colour for the experimental output and blue colour for the control output.

Findings from Experimental Study Conducted in Kalvilan GND

Upon scrutinizing the study findings for the household situated in Kalvilan, it was observed that the average temperature and humidity levels in the region varied from 22°C to 34°C. The maximum plant heights were measured at different stages of the four-phase life cycle, which were 3.5 cm in Phase I, 14 cm in Phase II, 22 cm in Phase III, and 32 cm in Phase IV. In contrast, the experimental trial was conducted in a controlled environment using modern technologies in a greenhouse, where the temperature and humidity levels were maintained between 21°C and 36°C during all four stages of the life cycle. The maximum plant heights observed in the experimental trial were 4 cm in Phase I, 18 cm in Phase II, 30 cm in Phase III, and 42 cm in Phase IV. Moreover, fruiting was observed during Phase IV of the growth cycle. In the control trial, three fruits were obtained, with a combined weight of 78 grams. In contrast, the experimental trial yielded six fruits with a total weight of 195 grams.

The study findings from the household situated in Kalvilan provide valuable insights into the impact of environmental conditions on plant growth and development. The results suggest that a controlled environment can promote higher plant growth rates and yields compared to natural conditions. Moreover, modern technologies can play a significant role in achieving these results. This research has the potential to contribute to the agricultural sector by promoting the use of controlled environments and advanced technologies to improve plant growth and production efficiency. Refer to *Annexure 3* for a detailed breakdown on productivity assessments.

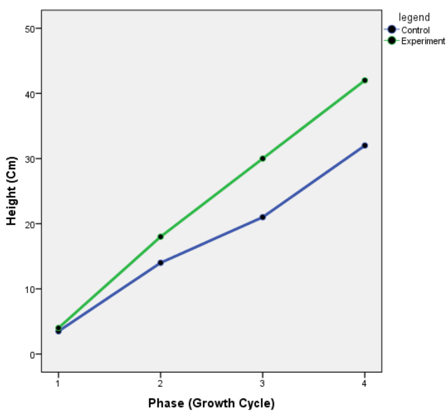

Figure 16. Height Comparison in between control and Experimental trials, Kalvilan, Mullaitivu

Source: (Author,2022)

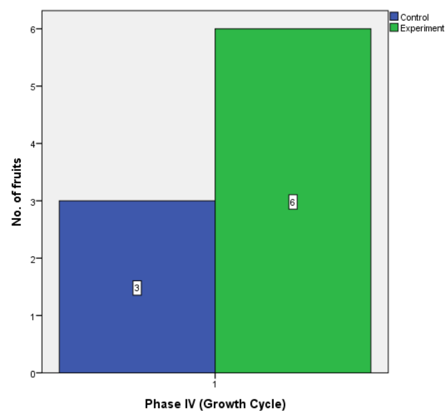

Figure 17. Fruiting Comparison in between control and Experimental trials, Kalvilan, Mullaitivu

Source: (Author,2022)

Note 8*:* The graph denotes green colour for the experimental output and blue colour for the control output.

Hypothetical Cost-Benefit Analysis

Agriculture is one of the main sectors that significantly impact the economy. This study seeks to assess the cost-benefit analysis of two agricultural methods: hydro greenhouse and traditional farming. The analysis is based on a 90-day forecast for both methodologies.

The hydro greenhouse system is more technology-intensive with a higher initial capital expenditure. The total setup cost, which includes the greenhouse, hydroponic system, and photosynthetically active radiation diode, for a capacity of 20 plants amounts to Rs. 24,000. The operating expenditure over the 30-day experimental period totals Rs. 600, with significant components being fertilizer cost of Rs. 300, and electricity costs of Rs.300. The production capacity of the hydro greenhouse system was determined to be 4000 grams of chillies per month, resulting from 20 plants, each yielding an average of 200 grams of yield per plant. The monthly revenue, calculated from the retail price of Rs. 40[3] per 100 grams of chillies, equates to Rs. 1,600 (Central Bank of Sri Lanka [CBSL], 2022). Over the 90-day period, the revenue totals Rs. 4,800. The monthly operating expenditure of Rs. 600 is significantly lower than the monthly revenue of Rs. 1,600, leading to a forecasted profit of Rs. 1,000 per month. Given these figures, the initial capital expenditure of Rs. 24,000 can be recovered in approximately 24 months.

In a similar vein, the hydro greenhouse system, configured to accommodate 40 plants, necessitates an initial setup cost of Rs. 26,000. This encompasses the cost of establishing the greenhouse, the hydroponic system, and the installation of a photosynthetically active radiation diode. The operational expenses over the designated 30-day experimental period accumulate to Rs. 600. Notable costs include the expenditure on fertilizers, amounting to Rs. 300, and the charges incurred for electricity, totaling Rs. 300. In terms of output, the hydro greenhouse system is estimated to yield 8000 grams of chillies per month, sourced from 40 plants, each producing an average of 200 grams of harvest per plant. The computation of the monthly revenue, drawn from the prevailing retail price of Rs. 40 per 100 grams of chillies, totals Rs. 3,200 (CBSL, 2022). Extended over the 90-day period, the cumulative revenue ascends to Rs. 9600. The monthly operational expenditure quantified at Rs. 600, is markedly lower than the monthly revenue of Rs. 3,200, forecasting a profit margin of Rs. 2600 per month. Given these parameters, it is estimated that the initial capital investment of Rs. 26,000 can be recuperated within a period of approximately 10 months. Consequently, despite the higher initial investment, the hydroponic greenhouse system displays promising financial prospects.

In contrast, traditional farming for an average plant capacity of 5, requires a lower initial outlay, as the only setup cost is Rs. 500 for seedling extraction. However, the operating expenditure over the 30-day period is higher at Rs.

[3] The retail price was sourced from the December 2022 price list provided by the Central Bank of Sri Lanka. The projection was formed based on the presumption that the price would remain steady for a period of 90 days commencing from December 2022.

1,000, mainly due to the cost of fertilizer Rs. 800, and insecticide/pesticide Rs. 200. The monthly yield is significantly lower in the traditional setup, producing only 405 grams of chillies from five plants with an average weight of 81 grams of yield per plant. At a retail price of Rs. 40 per 100 grams of chillies, the monthly revenue, is forecasted to be Rs. 162, and the total revenue over the 90-day period is Rs. 486. The monthly operational cost of Rs. 1,000 far exceeds the revenue of Rs. 162, resulting in a net loss of Rs. 838 per month.

Correspondingly, conventional farming practices for an average capacity of 25 plants necessitate a modest initial investment, with the sole setup expense being Rs. 500 for the extraction of seedlings. Nonetheless, the operational costs incurred over the course of the 30-day period are more substantial, totaling Rs. 1,000. This is largely attributed to the expenditure on fertilizers, which amounts to Rs. 800, and the cost of insecticides/pesticides, totaling Rs. 200. In stark contrast to the hydroponic system, the traditional setup yields a significantly lower output, producing a mere 2025 grams of chillies per month from 25 plants, each yielding an average of 81 grams per plant. Consequently, the monthly revenue is forecasted to be Rs. 810 at a retail price of Rs. 40 per 100 grams of chillies, and when extrapolated over the 90-day period, the cumulative revenue amounts to Rs. 2,430. However, the monthly operational cost, which is Rs. 1,000, substantially outstrips the revenue of Rs. 810, thereby resulting in a net deficit of Rs. 190 per month. Therefore, despite the lower initial investment, traditional farming practices prove to be less economically viable under the given conditions.

The productivity and profitability of the hydro greenhouse approach far surpass those of the conventional approach. Despite the increased initial investment, superior returns and a shorter payback period make the hydro greenhouse system more sustainable. An increase in the crop capacity within the hydro greenhouse system correlates with an increase in yield, which in turn accelerates the decline in the break-even period. On the other hand, traditional farming methods, despite their lower initial investment, are not financially viable given their operational costs and low yields. Even with increased plant capacity, the traditional farming method continues to run at a significant loss. Therefore, based on this cost-benefit analysis, the hydro greenhouse system with a maximum number of plants is the most profitable and sustainable option. It's crucial to consider that this analysis assumes stable market prices, consistent weather conditions, negligible pest issues, stable yields, and no substantial changes in operational costs. The detailed financial breakdown of the cost-benefit analysis can be found in *Annexure 4*.

Note 9: In the cost-benefit analysis, the mean weight of the harvest on the 90^{th} day, as derived from all three households, was utilized as an estimate for the expected harvest weight over the subsequent 90-day period.

Note 10: To accommodate a larger capacity of barrels within the greenhouse, a longitudinal extension of the greenhouse will have to be necessitated, expanding the original length of 1-metre to a total of 5-metre.

Note 11: The Photosynthetically Active Radiation Diode is characterized by a maximum illumination capacity of $1m^2$. During the experimental trial, the expansion in the plant capacity to accommodate 40 units necessitates an expansion of the internal area of the greenhouse construction from $1m^2$ to $5m^2$. Consequently, the spatial footprint of the hydroponic system under these conditions is projected to be $4m^2$. In the context of this expansion, it is noted that the total quantity of Photosynthetically Active Radiation Diodes required to adequately illuminate the increased crop area would amount to two.

Strategic Relevance of Hydro Greenhouse

Upon detailed analysis of the strategic relevance of the hydro greenhouse, the subsequent strengths, weaknesses, opportunities, and threats were identified.

Strengths of the *Hydro Greenhouse*:

Optimized Land Utilization: The incorporation of a hydroponic system within the hydro greenhouse presents an effective solution for the optimal use of land, a factor of critical importance in a region such as Mullaitivu. Current estimates indicate that approximately 70% of the land in this area is either underutilized or managed ineffectively, highlighting the importance of such innovative agricultural practices.

Water Preservation: The hydro greenhouse represents an innovative technology for the conservation of water resources. Notably, it is observed that an average plant within this system consumes only 1.4 litres of water, a stark contrast to the control setup which demands a significantly higher volume of approximately 5.6 litres or more.

Economic Advantage: The technological innovation offered by the hydro greenhouse presents a substantial cost benefit in terms of monthly fertilizer expenses. Specifically, it does not exceed Rs. 300, a markedly lower sum compared to the traditional control setup, which incurs a cost of Rs. 800.

Controlled Environment: The greenhouse integrated into the aforementioned technology offers a controlled environment. This significantly reduces the risks tied to unforeseeable weather fluctuations, as well as the incidence of pests and diseases, thereby promoting more stable and reliable agricultural outcomes.

Substantial Agricultural Reliance: With more than 62% of households reliant on agriculture, there is a clear indication of a robust local market for agricultural products, emphasizing the importance of continued innovation and support in this sector.

Weaknesses of *Hydro Greenhouse*:

Required Expertise: The management of hydroponic systems and photosynthetically active radiation necessitates a degree of technical knowledge and skills. According to the results of preliminary research carried out across the Mullaitivu District, a significant proportion, averaging over 70% of farmers, are aged above 50 years. This demographic reality potentially constrains their capacity to adapt to new technological practices.

Significant Startup Expenses: As delineated in the previous methodology section, the hydro greenhouse comprises three principal components: a hydroponic system, a greenhouse, and a setup for a photosynthetically active radiation-emitting diode. The projected installation cost stands at Rs.24,000, as per the cost analysis data from January 2022. Therefore, it can be deduced that the initial setup of hydroponic systems and greenhouses is a capital-intensive endeavour.

Energy Requirements: The running costs of the technological intervention notably include electricity consumption. The technology predominantly relies on a hydroponic system that necessitates the operation of a motor at a voltage of 220V-240V50Hz with a power of 50W. This system consumes an average of 43 units of electricity per month, thereby resulting in a significant portion of the overall cost being dedicated to electricity.

Opportunities of *Hydro Greenhouse*:

Productivity Enhancement: The fruiting stage commences subsequent to Phase III of the growth cycle. In the experimental setup, plant growth at the end of Phase IV demonstrates an increase in efficiency averaging more than 25% compared to the control setup. Concurrently, the fruiting efficiency in the experimental setup surpasses the control set up by 100%. Thus, the integration of this technology holds the potential to substantially elevate agricultural productivity, thereby bolstering the local economy and promoting food security.

Employment Opportunities: The technology elucidated above is characterized as an in-house method. Given that the majority of households in the area rely on farming as their primary source of livelihood, which is predominantly male-driven, this technology presents a valuable opportunity for females within these households to pursue self-employment. Furthermore, the overall impact of this study is the potential to foster skill development within the region.

Potential for Export: The hydro greenhouse yields produce that is entirely free from exposure to insecticides, pesticides, or other similar repellents. Additionally, the plants cultivated within the hydro greenhouse are safeguarded against any potential microbial, bacterial, or fungal attacks. As a result, the high quality of the produce is preserved, paving the way for prospective export opportunities, which could, in turn, generate additional revenue.

Threats of *Hydro Greenhouses*:

Political Instability: The introduction of the aforementioned technological intervention fosters a self-sustaining economy. However, the political framework in Sri Lanka exhibits a degree of resistance towards such self-reliance at the household level. This resistance can potentially disrupt operational efficiency.

Resistance to Change: Considering that more than 70% of the farmers are aged over 50, age becomes a constraining factor in technology adoption. These local farmers display resistance toward the uptake of this novel technology, which may be attributed to a lack of comprehension or an inherent fear of change.

Resource Availability: The restricted availability of essential resources such as water and electricity could present considerable obstacles to the successful implementation of the technology.

Impacts of Climate Change: Alterations in weather patterns as a result of climate change could potentially influence the efficacy or viability of greenhouse operations.

Discussion and Conclusion

Consistency of the research

The experimental trial that is being conducted by the researcher in the context of Mullaitivu District, Sri Lanka is based on a stratified simple random sampling. The experiment was conducted mainly across three main GNDs in the Thunukai DS Division each of which has a distinct geographical, behavioural, and psychological feature that is representable to that of the GNDs in all other DS Divisions within the Mullaitivu District. The sample of three GNDs, namely Kalvilan, Yogapuram East, and Mallavi, were three primary strata that had comparable features with the other GNDs; hence, one household from each stratum was chosen, and the experimental and control trials were carried out. Furthermore, under the control trial, the households were not provided with any technical interventions. The experimental trial in each household was provided with technical intervention. The interventions which were tested in the experiment were *the hydro greenhouse* (a technique developed by the author which includes a greenhouse, hydroponic system, and externally supplied photosynthetically active radiation). The output of the experimental trial with technical intervention showed high productivity compared with the control trial with no technical intervention. The experimental trial produced a greater yield in terms of height and fruiting than the control trial. The amount of water delivered to the control system was observed to be 1mm, that is 1 litre of water per metre squared. The daily water usage under the control trial is 4 litres, while the weekly total consumption is 28 litres. The average volume of plants grown in a 1-metre squared area is 5. In conclusion, one plant consumes 5.6 litres of water every week on average. The water supplied to the experimental trial was 7 litres per week, and the maximum number of crops that can be planted in one Hydroponic system (this mainly refers to the upper barrel in the hydroponic system) is 5 plants. Hence, the average water consumption of one plant is 1.4 litres per week. Furthermore, the cost of fertilizer (Urea + synthetic fertilizer) for the control trial ranged between Rs.800 per month, whereas the cost of fertilizer (Albert Solution) for the experimental trial was Rs.300 per month. Furthermore, the plants in the control trial received a maximum of 12 hours of natural sunlight, whereas the plants in the *hydro greenhouse* received a maximum of 12 hours of natural sunlight and 05 hours of photosynthetically active radiation. In the experimental trial, flowering and fruiting occurred substantially speedier than in the control trial. In summary, based on the experimental findings, it can be concluded that the implementation of a hydro greenhouse technology, has resulted in increased productivity, a significant reduction in farming expenditure along with a subsequent downfall in water utilization.

The Technology Acceptance Model (TAM) is a theoretical model that evaluates factors influencing the acceptance and implementation of new technologies. The model underscores perceived usefulness and ease of use as primary determinants of technology adoption. This study’s results on hydro greenhouse technology, comprising hydroponic systems, greenhouses, and photosynthetically active radiation, align with the TAM. The technology displayed considerable enhancements in productivity, cost-efficiency, and water conservation compared to conventional farming methods, indicating its perceived usefulness among farmers. Furthermore, the technology proved easy to operate with appropriate training, reinforcing the concept of perceived ease of use. The findings suggest a likely widespread acceptance and adoption of this technology in the agricultural sector, supporting the TAM. The technology's alignment with its agricultural context reinforces the model's assertion that the compatibility between technology and its environment influences its acceptance.

Nevertheless, the study provides evidence that technological interventions, such as the hydro greenhouse that comprises of Hydroponic system, Greenhouse, and Photosynthetically Active Radiation, can serve as an efficacious means of boosting agricultural productivity while minimizing resource usage.

Outliers in the Experiment

In the norm, the outliers are seldom significant, and the representation of such outliers is mostly useless. To attain a comprehensive insight, a few outliers observed in the experiment conducted are listed below:

- The experiment was conducted from August 2022 to November 2022. The plants were initially grown in nursery pots from May 2022 till July 2022. The seeds develop in 10-15 days, the seeds which were obtained from the agricultural office, Agri shops were largely infertile. Afterward, the chilli seeds were extracted from the chilli crops in the Mullaitivu region and a marginal capacity of 100g seeds were taken from the fruits, dried in the sunlight for 24 hours, moisturized, and placed in the breeding beds for growth. The seeds extracted from chilli fruits from previously grown plants showed a fertility rate of more than 95%.

- During the cultivation process in the control trial, the plants displayed a fungal growth on the upper surface of the leaves that was caused by ants, which were observed to be the substrate through which the fungus was transmitted (the ants around the area of the control trial appeared with a white attachment on their body). The above problem was resolved by the farmers in Mullaitivu by sprinkling soap water mixed with burned wood ashes over the lower and upper surfaces of the leaves.

- The farmers were emotionally convinced by the corporate representatives that synthetic fertilizers are high yielding and non-harmful. Synthetic fertilizers, on the other hand, are mostly composed of minerals and synthetic chemicals that, in the long term, damage soil fertility. It was startling to see that the spokesman in the GNDs subjected to the trial were government officials promoting chemical fertilizers.

- The family assigned to the experimental setup at Yogapuram East consisted of only 2 individuals, a husband, and a wife. Both were beyond the age of 70. The control experiment yielded initial results after 68 days, with the key observation in the household is that the farmer in the household has a routine practice where every day in the morning and night, the farmer speaks to the plants in his vicinity for at least 5 hours, perceiving the plants as his own children. The fruiting in many other plants around his land produced a greater yield than the neighbourhood in the vicinity.

Limitations in the experiment

The key limitations whichever were experienced by the authors are,

- The experimental study on modern agricultural techniques is an advanced approach among farming households in the Mullaitivu region. The people in the regions of Mullaitivu District have experienced war, which has largely affected the psychological balance among the farmers and has resulted in a gradual deterioration of their critical thinking (evidence from the preliminary study conducted). The author's practical constraint in reaching out to the households is reducing the psychological anxiety that existed among the farmers and convincing them to embrace the initiative to install the contemporary agricultural technique[4].

4 The DS officer of Thunukai DS has extended the support to accommodate the farming households across the GNDs to define the scope of the experimental study carried out by the author.

- The residents of the Mullaitivu District are illiterate and reckless. Despite being educated on the processes to follow in the experiment trial, the experiment failed a number of times since February 2022[5] owing to the people's ignorance.

- There is a scarcity of water in Mullaitivu. The household relies heavily on rainfall since subterranean water is laden with magnesium, which has a detrimental impact on plant development. Farmers collect rainwater from water reserves, primarily dams, and reservoirs. As a result, the households found it difficult to allocate an average of 35 litres of water weekly for both the control and experimental trial[6].

Significance of the Study

The author's experimental research in a war-torn region of Sri Lanka is a pioneering study in the vicinity of the Northern Province since experimental studies were limited in the vicinity of the Northern Province. As a result, the study on advanced growing techniques serves as an eye-opening for stakeholders in Northern Province. The advanced growing technique used in the Northern Province implies a low budget in production to make the growing technique affordable for every household in the Northern Province. The experimental study suggests that the presence of a hydroponic system within a greenhouse environment with photosynthetically active radiation yields a much greater yield in terms of plant height and fruit yield than the control trial. The experiment research supports and serves as a benchmark for other disciplines of science in undertaking additional biological and non-biological advancement aimed at increasing cultivable yield. Furthermore, the study depicts the distribution of unutilized and underused land resources, which account for an average of 69.18% of lands in Northern Province (CSSNP, 2017; CSSNP, 2018; CSSNP, 2019; CSSNP, 2020). The experimental trial provides a safety net from fungal and bacterial infection for the plants created by the external agents, mainly ants. Furthermore, as hydroponics is a water-saving approach, it reduces water consumption per plant from 5.6 litres to 1.4 litres per week. Furthermore, the nutrient film approach in a hydroponic system, combined with

5 Later, the situation was resolved by engaging the farmers as hired laborers, with the author paid a monthly compensation to farming households until the completion of 90 days. The actual commencement began on August 18, 2022.

6 The water scarcity for the experiment conducted was fulfilled by the support aided by the neighbours in the vicinity of the sampled households.

photosynthetically active light in a wavelength range of 650nm-720nm, resulted in better flowering and fruiting than the control trial (statistics are already provided under the Table 4 to Table 6). The study findings indicate an opportunity for farming households to open a new avenue to increase productivity, and for agricultural vendors to diversify their business from traditional sales of fertilizer and plants to selling necessary equipment and utensils for the construction of Ponic Systems/Advanced Agricultural Techniques. The study findings point to a new era of unisex agriculture in which women's empowerment may be maximized as agricultural growing techniques examined by the author are primarily cultivated in-house. Overall, the use of modern farming techniques yields high productivity and thus contributes to GDP. On the other hand, the results of the experimental study assist undergraduate and postgraduate students in the fields of development economics and agriculture in fulfilling the knowledge gaps on modern agricultural techniques and generalizing the experimental findings across all the districts in the Northern Province of Sri Lanka. The findings can be used by research institutes and finance institutions, both governmental and non-governmental, to benchmark the author's experiment in order to launch economically sustainable initiatives in the field of agriculture.

Future Study Directions

The experimental study focuses mainly on the impact of the greenhouse, as well as the hydroponic system that supplies photosynthetically active radiation to the plants. The study was focused on photosynthetically active radiation at the wavelength of 650-720 nm which actively absorbs chlorophyll-a and a significant proportion of phycocyanin. The study fails to analyse the influence of different photosynthetically active radiation wavelengths other than 650-720 nm on shoot growth, blooming, and fruiting, i.e., the wavelengths that boost the absorption of chlorophyll-b, carotenoids, phycoerythrin, and phycocyanin. The nutrient film technique was employed in the hydroponic system experiment; the study was not focused on the wick, drip, ebb flow, and deep-water green techniques, which are additional hydroponic system techniques used across the industrialized world. The greenhouse can be categorized into twelve common structures – gable, flat arch, tunnel, dome, sawtooth, skillion, uneven, ridge & furrow, lean-to, tripenta, gothic, and A-frame. The experiment conducted by the author is based on an uneven greenhouse technique. The experiment on the rest of the structures and the influence of their application on productivity are still untouched. The above discussion opens the avenue for future researchers to explore deeper on the advanced growing systems equipped with the hydroponic, greenhouse along with the externally supplied photosynthetically active radiation diode.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

References

Abeywardana, N., Schütt, B., Wagalawatta, T., & Bebermeier, W. (2019). Indigenous agricultural systems in the dry zone of Sri Lanka: management transformation assessment and sustainability. *Sustainability, 11*(3), 910.

Adelaja, A. (2003). The 21st-century land grant economist. *Agricultural and Resource Economics Review, 32*(2), 159-170.

Alshrouf, A. (2017). Hydroponics, aeroponic, and aquaponic as compared with conventional farming. *American Scientific Research Journal for Engineering, Technology, and Sciences, 27*(1), 247-255.

Arnade, C. (1998). Using a programming approach to measure international agricultural efficiency and productivity. *Journal of Agricultural Economics*, *49*(1), 67-84.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management, 17*(1), 99-120.

Beintema, N. M., Zambrano, P., Nunez, M., & Pardey, P. (2000). *Agricultural R&D in Paraguay: Policy, Investments, and Institutional Profile.* Washington, D.C: International Food Policy Research Institute.

Bennett, R., & Birol, E. (2010). Choice experiments in developing country agriculture: State of the evidence and research agenda. *Agricultural Economics*, *41*(2), 153-16.

Besag, J., & Higdon, D. (2002). Bayesian analysis of agricultural field experiments. *Journal of Agricultural, Biological, and Environmental Statistics*, *7*(4), 381-430.

Butler, A. W., & Cornaggia, J. (2011). Does access to external finance improve productivity? Evidence from a natural experiment. *Journal of Financial Economics*, *99*(1), 184-203.

Central Bank of Sri Lanka [CBSL]. (2022). *Price Report - December*. https://www.cbsl.gov.lk/sites/default/files/cbslweb_documents/statistics/pricerpt/price_report_20221201.pdf.

Chief Secretary's Secretariat – Northern Province [CSSNP]. (2017). *Statistical Information Northern Province.* Jaffna.

Chief Secretary's Secretariat – Northern Province [CSSNP]. (2018). *Statistical Information Northern Province.* Jaffna.

Chief Secretary's Secretariat – Northern Province [CSSNP]. (2019). *Statistical Information Northern Province.* Jaffna.

Chief Secretary's Secretariat – Northern Province [CSSNP]. (2020). *Statistical Information Northern Province.* Jaffna.

Crawford, M. L., Williamson, P. S., Waliczek, T. M., Lemke, D. E., & Hardy, T. B. (2020). Effects of Photosynthetically Active Radiation on Vegetative Growth of Texas Wild Rice and Consequences for Population Augmentation. *American Society for Horticultural Science, 55*(7), 1000-1004.

Davis, F. D. (1986). *A technology acceptance model for empirically testing new end-user information systems: Theory and results.* Massachusetts Institute of Technology.

Department of Census & Statistics [DCS]. (2011). *Household Income and Expenditure Survey - 2009/10*. Ministry of Finance and Planning. Colombo: Samples Survey Division, Department of Census and Statistics.

Department of Census & Statistics [DCS]. (2015). *Household Income and Expenditure Survey - 2012/13*. Ministry of Policy Planning Economic Affairs, Child Youth and Cultural Affairs. Battaramulla, Sri Lanka: Samples Survey Division, Department of Census and Statistics.

Department of Census & Statistics [DCS]. (2018). *Household Income and Expenditure Survey - 2016*. Ministry of National Policies and Economic Affairs. Battaramulla, Sri Lanka: Samples Survey Division, Department of Census and Statistics.

Department of Census & Statistics [DCS]. (2019). *Global Multidimensional Poverty for Sri Lanka*. Ministry of Economic Reforms and Public Distribution. Battaramulla, Sri Lanka: Samples Survey Division, Department of Census and Statistics.

Department of Census & Statistics [DCS]. (2022). *Household Income and Expenditure Survey - 2019*. Ministry of Economic Policies and Plan Implementation. Battaramulla, Sri Lanka: Samples Survey Division, Department of Census and Statistics.

Dhrifi, A. (2013). Agricultural Productivity and Poverty Alleviation: What Role for Technological Innovation. *Journal of Economic and Social Studies, 4*(1), 139-154.

Food and Agriculture Organization of the United Nations [FAO]. (2017). *The future of food and agriculture: Trends and challenges*. Rome. Retrieved from http://www.fao.org/3/a-i6583e.pdf.

Food and Agriculture Organization of the United Nations [FAO]. (2018). *Country Gender Assessment of Agriculture and the Rural Sector in Sri Lanka*. Colombo.

Newhouse, D. L., Suarez Becerra, P., & Doan, D. (2016). *Sri Lanka Poverty and Welfare: Recent Progress and Remaining Challenges*. World Bank, Washington, DC. http://hdl.handle.net/10986/23794.

Fuglie, K., & Rada, N. (2013). Resources, policies, and agricultural productivity in sub-Saharan Africa. *USDA-ERS Economic Research Report*, (145)

Fulginiti, L., & Perrin, R. K. (1997). LDC Agriculture: Non parametric Malmquist Productivity Indexes. *Journal of Development Economics*, *53*(2), 370-388.

Government UK. (2011). The Future of Food and Farming: Executive Summary. London: United Kingdom Government Office for Science.

Ghadim, A. K., & Pannell, D. J. (1999). A conceptual framework of adoption of an agricultural innovation. *Agricultural economics, 21*(2), 145-155.

Ghosh, S., Ray, S., & Chatterjee, A. (2020). Improvement of yield and quality of chilli using hydroponic farming: A review. *Journal of Horticultural Science and Technology*, *2*(2), 29-36.

Hara, A. T., & Turssi, C. P. (2017). Baking soda as an abrasive in toothpastes: Mechanism of action and safety and effectiveness considerations. *The Journal of the American Dental Association, 148*(11), 20-40.

Holden, R. J., & Karsh, B. T. (2010). The technology acceptance model: its past and its future in health care. *Journal of biomedical informatics*, *43*(1), 159-172.

Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S., & Venkataraman, G. (2018). CRISPR for Crop Improvement: An Update Review. *Frontiers in plant science*, *9*, 985.

Javed, M. T., Haider, A., & Nawaz, M. A. (2020). Adaptation strategies employed in the agricultural sector in response to climate change: A case study of Pakistan. *Environmental Science and Pollution Research*, *27*(8), 7804-7816.

Jayne, T., Mather, D., & Mghenyi, E. (2010). Principal challenges confronting smallholder agriculture in Sub-Saharan Africa. *World Dev, 38*(10), 1384-1398.

Kamilaris, A., Prenafeta-Boldύ, F. X., & Katsikas, L. (2017). Deep learning in agriculture: A survey. *Computers and Electronics in Agriculture*, *147*, 70-90.

King, W. R., & He, J. (2006). A meta-analysis of the technology acceptance model. *Information & Management*, *43*(6), 740-755.

Kim, J., & Kim, J. S. (2016). Bypassing GMO regulations with CRISPR gene editing. Nature Biotechnology, 34(10), 1014-1015.

Klerkx, L., Aarts, N., & Leeuwis, C. (2010). Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. *Agricultural Systems*, 390-400.

Laria, J., Meza, E., & Pena, J. L. (2007). Water and calcium uptake by corn kernel during alkaline treatment with different temperature profiles. *Journal of Food Engineering, 78*(1), 265-290.

Lederer, A. L., Maupin, D. J., Sena, M. P., & Zhuang, Y. (2000). The technology acceptance model and the World Wide Web. *Decision support systems*, *29*(3), 269-282.

Lee, D. (2005). Agricultural Sustainability and Technology Adoption: Issues and Policies for Developing Countries. *American Journal of Agricultural Economic, 87*(5), 1325-1334.

Lee, Y. H., Wang, K. H., Park, C. B., & Sain, M. (2007). Effects of clay dispersion on the foam morphology of LDPE/clay nanocomposites. *Journal of applied polymer science, 103*(4), 2129-2134.

Li, X., Wang, K., Liu, L., Xin, J., Yang, H., Gao, R., & Zhou, C. (2019). Farmers' intention to dismantle abandoned plastic greenhouses: application of an extended theory of planned behaviour model. *Land use policy*, *82*, 299-307.

Lv, J., & Liu, Y. (2019). An integrated approach to identify quantitative sources and hazardous areas of heavy metals in soils. *Science of the Total Environment*, *646*, 19-28.

Makate, C. (2019). Effective scaling of climate smart agriculture innovations in African smallholder agriculture: A review of approaches, policy and institutional strategy needs. *Environmental science & policy*, *96*, 37-51.

Marangunic, N., & Granic, A. (2015). Technology acceptance model: a literature review from 1986 to 2013. *Universal access in the information society*, *14*, 81-95.

Matsuyama, K. (1992). Agricultural productivity, comparative advantage, and economic growth. *Journal of economic theory*, *58*(2), 317-334.

Mottus, M., Sulev, M., Baret, F., Lopez-Lozano, R., & Reinart, A. (2013). Photosynthetically active radiation: measurement and modelling. In *Solar energy* (pp. 140-169). Springer, New York, NY.

Murphy, K. M., Shleifer, A., & Vishny, R. (1989). Income distribution, market size, and industrilization. *Quart. Journal of Economics, 104*, 537-564.

Paiva, P., & Gazel, R. (2004). MERCOSUR Economic Issues: Successes, Failures and Unfinished Business, Center for Latin American Studies. *CLAS Working Papers, Paper 5*.

Parker, R., Ramdas, K., & Savva, N. (2016). Mobile phones, mediation, and social networks in rural India: A study of the effects of mobile phone coverage on market participation by small farmers. *Journal of International Development*, *28*(5), 819-836.

Parry, M. L., & Carter, T. R. (1989). Climate impact assessment: General framework and methodology. In M. L. Parry & T. R. Carter (Eds.), Climatic impact assessment: Proceedings of the IPCC Workshop held in Laxenburg, Austria, 22-26 February 1988 (pp. 9-22). Cambridge University Press.

Ponisio, L. C., M'Gonigle, L. K., Mace, K. C., Palomino, J., de Valpine, P., & Kremen, C. (2015). Diversification practices reduce the organic to conventional yield gap. Proceedings of the Royal Society B: *Biological Sciences*, *282*(1799), 20141396.

Penrose, E. T. (1959). *The theory of the growth of the firm.* Oxford University Press.

Ponce, P., Molina, A., Cepeda, P., Lugo, E., & MacCleery, B. (2014). In *Greenhouse design and control* (Vol. 411). Boca Raton, Florida, USA: CRC press.

Rogers, E. M. (1962). *Diffusion of Innovations.* New York: Free Press.

Rose, D. C., Sutherland, W. J., Parker, C., Lobley, M., Winter, M., Morris, C., Twining, S., Ffoulkes, C., Amano, T., & Dicks, L. V. (2018). Decision support tools for agriculture: Towards effective design and delivery. *Agricultural Systems*, *149*, 165-174.

Sayer, J., & Cassman, K. G. (2013). Agricultural innovation to protect the environment. *Proceedings of the National Academy of Sciences, 110*(21), 8345-834.

Sharma, N., Acharya, S., Kumar, K., Singh, N., & Chaurasia, O. P. (2018). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation, 17*(4), 364-371.

Son, J. E., Kim, H. J., & Ahn, T. I. (2020). Hydroponic systems. In *Plant factory*, *1*, 273-283. Academic Press.

Splawa-Neyman, T., Guttman, L., Wilks, S. S., & Lehmann, E. L. (1990). The founding of the Journal of the American Statistical Association: The background and early years (1922–1935). *Journal of the American Statistical Association*, *85*(410), 19-26.

Sunding, D., & Zilberman, D. (2001). The agricultural innovation process: research and technology adoption in a changing agricultural sector. *Handbooks in Economics, 18*(1A), 207-262.

Trejo-Tellez, L. I., & Gomez-Merino, F. C. (2012). Nutrient solutions for hydroponic systems. *Hydroponics - a standard methodology for plant biological researches*, *1*, 1-22

Vance, C. (2000). Productivity of agricultural sites: A case study. *Journal of Agricultural Economics*, *51*(2), 257-271.

Von Zabeltitz, C. (2011). Integrated Greenhouse Systems for Mild Climates: Climate Conditions, Design, Construction, Maintenance, Climate Control. *Greenhouse structures*, 59-135.

Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal, 5*(2), 171-180.

Wortman, S. E. (2015). Crop physiological response to nutrient solution electrical conductivity and pH in an ebb-and-flow hydroponic system. *Scientia Horticulturae, 194*, 34-42.

Yang, R. (2010). Modelling correlated continuous agricultural data using a mixed effect model PROC MIXED of the SAS system. *Journal of Agricultural, Biological, and Environmental Statistics, 15*(2), 131-150.

Zhang, N., & Kovacs, J. M. (2012). *The application of small unmanned aerial systems for precision agriculture: a review*. Precision agriculture, *13*(6), 693-712.

Zilberman, D., Schmitz, A., Casterline, G., Lichtenberg, G., & Siebert, J. (1991). *The economics of pesticide use and regulation.* Berkeley: Department of Agricultural and Resource Economics, University of California.

Annexure

Annexure 1

Table 4 Experimental Study Output for Mallavi, Mullaitivu

Location	Date	Temperature/ Humidity	Productivity			Remark
			No.	Height	Fruits	
Mallavi, Mullaitivu	18.08.2022 *(Control Phase I)*	: 30°C : 21°C	Plant 1	5 cm	0	This is a control setup where the plant is being planted in the ground without any technological/technical intervention. The control setup is supplied with inorganic ions both in the form of solid and liquid. The main fertilizers supplied are urea along with synthetic fertilizers.
			Plant 2	4.5 cm		
			Plant 3	6 cm		
			Plant 4	6 cm		
			Plant 5	4 cm		
			Plant 6	5.5 cm		
			Plant 7	4 cm		
	07.09.2022 *(Control Phase II)*	: 32°C : 23°C	Plant 1	10 cm	0	
			Plant 2	7.5 cm		
			Plant 3	14 cm		
			Plant 4	14 cm		
			Plant 5	8 cm		
			Plant 6	12 cm		
			Plant 7	10 cm		
	26.09.2022 *(Control Phase III)*	: 28°C : 20°C	Plant 1	20 cm	0	
			Plant 2	12 cm		
			Plant 3	21 cm		
			Plant 4	21 cm		
			Plant 5	21 cm		
			Plant 6	22 cm		
			Plant 7	18 cm		
	19.11.2022 *(Control Phase IV)*	: 30°C : 23°C	Plant 1	30 cm	3	
			Plant 2	25 cm	0	
			Plant 3	35 cm	3	
			Plant 4	32 cm	3	
			Plant 5	30 cm	2	
			Plant 6	33 cm	3	
			Plant 7	29 cm	2	
Mallavi, Mullaitivu	18.08.2022 *(Experiment Phase I)*	: 32°C : 23°C	Plant 8	06 cm	0	This is an experimental trial; the plant is being planted inside a greenhouse supplied with photosynthetically

07.09.2022 *(Experiment Phase II)*	: 34°C : 25°C	Plant 8	16 cm	0	active radiation and a hydroponic system. The inorganic ions were supplied by the Albert solution once every two days. The detailed assessment of the fertilizer and proportion of quantity added to the nutrient solution are detailed in the methodology of the report above.
26.09.2022 *(Experiment Phase III)*	: 32°C : 24°C	Plant 8	31 cm	0	
19.11.2022 *(Experiment Phase IV)*	: 32°C : 20°C	Plant 8	45 cm	7	

Source: (Author, 2022)

Annexure 2

Table 5 Experimental Study Output for Yogapuram East, Mullaitivu

Location	Date	Temperature/ Humidity	Productivity No.	Productivity Height	Productivity Fruits	Remark
Yogapuram East, Mullaitivu	18.08.2022 *(Control Phase I)*	: 32°C : 22°C	Plant 1 Plant 2 Plant 3 Plant 4 Plant 5	5 cm 4 cm 5.5 cm 5 cm 4.5 cm	0	This is a control setup planted in the ground without any technological intervention. The control set up in Yogapuram East, Mullaitivu is supplied with the inorganic ions both in the form of solid and liquid. The main fertilizers supplied are urea along with synthetic fertilizer.
	07.09.2022 *(Control Phase II)*	: 34°C : 22°C	Plant 1 Plant 2 Plant 3 Plant 4 Plant 5	12 cm 9.5 cm 14 cm 12.5 cm 10 cm	0	
	24.09.2022 *(Control Phase III)*	: 31°C : 23°C	Plant 1 Plant 2 Plant 3 Plant 4 Plant 5	20 cm 22 cm 20 cm 15 cm 18 cm	0	
	15.11.2022 *(Control Phase IV)*	: 28°C : 21°C	Plant 1 Plant 2 Plant 3 Plant 4 Plant 5	26 cm 30 cm 29 cm 30 cm 25 cm	4 2 1 2 1	
Yogapuram East, Mullaitivu	18.08.2022 *(Experiment Phase I)*	: 34°C : 24°C	Plant 6	5 cm		This is an experimental trial; the plant is being planted inside the greenhouse supplied with photosynthetically active radiation and hydroponic system. The inorganic ions were supplied by the albert solution once in every two days. The detailed assessment on the fertilizer and proportion of quantity added to the nutrient solution are detailed in the methodology of the report above.
	07.09.2022 *(Experiment Phase II)*	: 36°C : 23°C	Plant 6	19 cm	0	
	24.09.2022 *(Experiment Phase III)*	: 35°C : 24°C	Plant 6	32 cm	0	
	15.11.2022 *(Experiment Phase IV)*	: 32°C : 23°C	Plant 6	40 cm	6	

Source: (Author, 2022)

Annexure 3

Table 6 Experimental Study Output for Kalvilan, Mullaitivu

Location	Date	Temperature/ Humidity	Productivity No.	Productivity Height	Productivity Fruits	Remark
Kalvilan, Mullaitivu	18.08.2022 *(Control Phase I)*	: 31°C : 22°C	Plant 1	3.5 cm	0	This is a control setup planted in the ground without any technological intervention. The control set up in Kalvilan, Mullaitivu is supplied with the inorganic ions both in the form of solid and liquid. The main fertilizers supplied are urea along with synthetic fertilizers.
			Plant 2	2.5 cm		
			Plant 3	3 cm		
			Plant 4	2 cm		
			Plant 5	2 cm		
	07.09.2022 *(Control Phase II)*	: 34°C : 22°C	Plant 1	12 cm	0	
			Plant 2	12.5 cm		
			Plant 3	11.5 cm		
			Plant 4	14 cm		
			Plant 5	12 cm		
	25.09.2022 *(Control Phase III)*	: 32°C : 22°C	Plant 1	20 cm	0	
			Plant 2	21 cm		
			Plant 3	17 cm		
			Plant 4	14 cm		
			Plant 5	22 cm		
	12.11.2022 *(Control Phase IV)*	: 32°C : 22°C	Plant 1	32 cm	2	
			Plant 2	27 cm	3	
			Plant 3	25 cm	2	
			Plant 4	24 cm	0	
			Plant 5	27 cm	2	
Kalvilan, Mullaitivu	18.08.2022 *(Experiment Phase I)*	: 34°C : 24°C	Plant 6	4 cm	0	This is an experimental trial; the plant is being planted inside the greenhouse supplied with photosynthetically active radiation and a hydroponic system. The inorganic ions were supplied by the Albert solution once every two days. The detailed assessment of the fertilizer and proportion of quantity added to the nutrient solution are detailed in the methodology of the report above.
	07.09.2022 *(Experiment Phase II)*	: 35°C : 24°C	Plant 6	18 cm	0	
	25.09.2022 *(Experiment Phase III)*	: 34°C : 21°C	Plant 6	30 cm	0	
	12.11.2022 *(Experiment Phase IV)*	: 36°C : 24°C	Plant 6	42 cm	6	

Source: (Author, 2022)

Annexure 4
Table 7 Cost Projection for 30 Days on Experimental Trial

	Experimental Trial	
	20 Chilli Plants (30 days)	40 Chilli Plants (30 days)
Cost / Expenditure	Rs.	Rs.
Capital Expenditure		
Greenhouse construction	12000.00	12000.00
Hydroponic System	10000.00	10000.00
Photosynthetically Active Radiation Diode	2000.00	4000.00
Cost of Extraction of the Seedlings *(Cost is fixed for the extraction of up to 100 grams of seeds)*	500.00	500.00
Operating Expenditure		
Cost of fertilizer	300.00	300.00
Cost of insecticide	0.00	0.00
Cost of electricity	300.00	300.00
Total Cost	**25100.00**	**27100.00**

Source: (Author, 2022)

Table 8 Cost Projection for 30 Days on Control Trial

	Control Trial	
	5 Chilli Plants (30 days)	25 Chilli Plants (30 days)
Cost / Expenditure	Rs.	Rs.
Capital Expenditure		
Greenhouse construction	0.00	0.00
Hydroponic System	0.00	0.00
Photosynthetically Active Radiation Diode	0.00	0.00
Cost of Extraction of the Seedlings *(Cost is fixed for the extraction of up to 100 grams of seeds)*	500.00	500.00
Operating Expenditure		
Cost of fertilizer	800.00	800.00
Cost of insecticide	200.00	200.00
Cost of electricity	0.00	0.00
Total Cost	**1500.00**	**1500.00**

Source: (Author, 2022)

Table 9 Profit Projection for 30 Days on Experimental Trial

	Experimental Trial	
	20 Chilli Plants (30 days)	40 Chilli Plants (30 days)
Revenue		
Yield per harvest per crop *(grams)*	200	200
Total Production *(grams)*	4000	8000
Revenue *(100 grams @ Rs.40) (Rs.)*	**1600.00**	**3200.00**
Operating Expenditure		
Cost of fertilizer *(Rs.)*	300.00	300.00
Cost of insecticide *(Rs.)*	0.00	0.00
Cost of electricity *(Rs.)*	300.00	300.00
Total *(Rs.)*	**600.00**	**600.00**
Profit	**1000.00**	**2600.00**

Source: (Author, 2022)

Table 10 Profit Projection for 30 Days on Control Trial

	Control Trial	
	5 Chilli Plants (30 days)	25 Chilli Plants (30 days)
Revenue		
Yield per harvest per crop *(grams)*	81	81
Total Production *(grams)*	405	2025
Revenue *(100 grams @ Rs.40) (Rs.)*	**162.00**	**810.00**
Operating Expenditure		
Cost of fertilizer *(Rs.)*	800.00	800.00
Cost of insecticide *(Rs.)*	200.00	200.00
Cost of electricity *(Rs.)*	0.00	0.00
Total *(Rs.)*	**1000.00**	**1000.00**
Loss *(Rs.)*	**-838.00**	**-190.00**

Source: (Author, 2022)