e-ISSN: 2550-1569

Available online at
https://myjms.mohe.gov.my/index.php/IJSMS

International Journal of Service Management and Sustainability
10(2) 2025, 140 – 160.

International Journal of Service Management and Sustainability (IJSMSust)

The Challenges of Vegetable Production Through Fertigation for Smallholder Farmers in Sarawak: A Qualitative Study

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ARTICLE INFO

Article history:
Received: 1 March 2025
Revised: 25 August 2025
Accepted: 27 August 2025
Online first
Published: 30 September 2025

Keywords:
Fertigation
Challenges
Smallholder Farmers
Rural Areas
Qualitative Research

DOI: 10.24191/ijsms.v10i2.24232

Citation in APA:
Daniel, M. M., Saili, A. R., Ahmed Sejali, N., Kamil, M. Z. & Abd Aziz, A. S. (2025). The challenges of vegetable production through fertigation for smallholder farmers in Sarawak: A qualitative study. *International Journal of Service Management and Sustainability, 10*(2), 140 – 160.

ABSTRACT

Fertigation is the process of applying liquid or soluble solid nutrients via an irrigation system, with the drips that flow directly to the root area of the plants. Small-scale farmers in the rural areas of Sarawak are working extremely hard to fulfil food demand and generate adequate crops to meet the necessities of their livelihood and families. Supporting rural communities and enabling them to meet the growing demand for food worldwide may be achieved by giving them the legal means to increase their food production and alleviate hardship. Even though fertigation is an advanced agricultural technology that is profitable and productive, farmers' adoption of these technologies is still challenging, particularly for farmers in rural areas. Therefore, qualitative research was carried out among the smallholder farmers in Sarawak rural areas to identify the challenges associated with the use of fertigation. The findings indicated that farmers faced some challenges related to pests and diseases, availability of materials, high initial startup costs, market fluctuations, material costs, climate change, lack of knowledge, and agricultural marketing. In addition, this research also covered the challenges mentioned by participants in implementing fertigation.

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1.0 INTRODUCTION

In recent years, fertile and productive soils have emerged as a key factor for the development of balanced civilisations and communities. According to Sureshkumar et al. (2017), nutritious and healthy soils are crucial for the ecosystem's energy security and water security, thus supporting the growth and development of plants that people consume as food. Precision farming technology, especially the fertigation system, plays an essential role for smallholder farmers globally, although it is often viewed as unfamiliar. Loon et al. (2018) demonstrate that adverse environmental changes mostly impact rural areas with limited resources. Besides, Kafkafi (2005) mentioned that the rising labour costs have accelerated the development of fertigation farming, the need to reduce pollution and erosion of the soil, greater dependence on water salinity supplies, wind circumstances, and the adverse quality of soil in some areas. As a result, smallholder farmers begin to look for the highest yield and often provide better food-based supplies to satisfy the need for food, even if there is a shift in the trend of the agricultural industry, impacted by the rise of the farming industry itself. According to Abdullah (2017), when rural communities and their inhabitants experience changes contributed by external factors like urbanisation, the desires and opportunities will also grow.

Fertigation, which is the integrated application of irrigation and soluble fertilisers through drip systems has emerged as a promising technology for improving productivity in horticulture. It allows precise nutrient management, optimises water use, and can enhance both yield and product quality compared to conventional methods. As stated by Hakkim et al. (2016), fertigation is a process of applying permeable solid fertilisers or liquid fertilisers via the drip irrigation method, which is injected directly into the region where the root systems are developing. Furthermore, Xiukang and Yingying (2017) mentioned that fertigation is a technique for managing agricultural activity that simultaneously supplies fertilisers and water in a system known as drip irrigation. The irrigation mechanism will transport the fertiliser into the root regions of the plant after adding the soluble fertiliser to the water source. For smallholder farmers in Sarawak, fertigation offers the potential to overcome soil limitations, reduce input wastage, and maintain continuous production throughout the year. Despite these advantages, the widespread adoption and success of fertigation remain constrained by a range of challenges specific to the local context.

Although fertigation is a beneficial way to provide crops with enough nutrients and other advantages, farmers in the rural areas in Sarawak also face certain difficulties after adopting and implementing the fertigation systems on their farms. Pests and diseases remain a persistent threat under intensive systems, while access to quality inputs and equipment is often limited and costly in rural areas in Sarawak. High startup investments and recurring material costs discourage smallholders from adopting fertigation on a larger scale. Market-related constraints, including price volatility and weak bargaining power, further reduce profitability. Moreover, Sarawak's humid tropical climate poses additional risks, with heavy rainfall and flooding affecting production cycles. Limited technical knowledge and gaps in extension support further hinder the farmers' ability to optimise fertigation practices, while inefficiencies in agricultural marketing restrict access to profitable markets.

Therefore, this study is essential to understand the viewpoint of farmers in rural areas on fertigation farming, including the challenges that they face when implementing smart farming techniques on their farms. While past research has examined fertigation determinants, few studies have explored the challenges faced by smallholder farmers in rural Sarawak. Despite being seen as less favourable for growth, Sarawak remains a key contributor to Malaysia's agriculture. This research can therefore serve as a guide for the relevant groups who require future support in fertigation farming.

This study aims to fill a gap in the field of research by addressing the difficulties experienced by farmers in implementing fertigation farming, especially for rural farmers in Sarawak, Malaysia. In order to enhance supply and demand as well as promote technological changes in Sarawak, these research findings are valuable to the government, researchers, legislators, educators, agriculture extension representatives, and other relevant organisations. Thus, qualitative research was carried out with the smallholder farmers in rural areas of Sarawak to figure out the challenges in implementing fertigation farming.

2.0 LITERATURE REVIEW

Vegetable production plays a critical role in global agriculture, contributing to food security, dietary diversity, income generation, and rural employment. Smallholder farmers rely on vegetable cultivation both for subsistence and as a source of cash income due to relatively short production cycles and strong market demand. However, vegetable production is highly vulnerable to multiple constraints that hinder productivity, profitability, and sustainability. Mazlan et al. (2020) stated that the challenges faced by smallholder pepper farmers in Sarawak include climate, worker shortage, government assistance, profit, pests and diseases. Besides, Kumar et al. (2024) also mentioned that the difficulties of vegetable growers, including insufficient information, problems with stray animals and wildlife, socio-economic concerns, counterfeit market inputs, lower vegetable prices, limited marketing facilities, as well as elevated labour and marketing costs, diminish farmers' net profits. These challenges are multidimensional, encompassing biophysical, economic, institutional, and socio-cultural barriers that often interact in complex ways. This is proven by Singh and Kameswari (2023), who mentioned that the financial limitations were the most significant barrier, followed by organisational, technical, marketing, and infrastructure barriers. Similar to the study of Tomar et al. (2023), the farmers encountered several obstacles during the establishment of grassroots innovations, including social, economic, technical, organisational, infrastructure, and marketing limitations. This literature review synthesises evidence on the significant challenges of vegetable production, organised under six thematic areas: biophysical constraints, input and capital limitations, market and economic challenges, knowledge and institutional barriers, post-harvest and value-chain issues, and socio-gender considerations.

In biophysical constraints, pests and diseases are consistently reported as the most critical constraints to vegetable production worldwide. Vegetables are vulnerable to insect pests, nematodes, and pathogens such as fungi, bacteria, and viruses, which cause significant yield and quality losses (Alemu, 2020). In tropical and subtropical climates, high humidity and temperatures facilitate rapid pathogen spread. Over-reliance on pesticides has contributed to environmental degradation and health risks (Phophi & Mafongoya, 2017). The limited adoption of integrated pest management (IPM) and restricted access to resistant varieties further exacerbate these challenges. Besides, declining soil fertility poses a significant threat to the sustainability of vegetable production. Continuous cultivation without adequate organic replenishment leads to nutrient depletion and reduced soil productivity (Aytenew & Wolancho, 2020). In many smallholder systems, farmers lack access to soil testing services, resulting in inappropriate fertiliser application. Imbalances in nitrogen, phosphorus, and potassium are common, while salinity, soil acidity, and compaction further reduce yields. In addition, vegetables require a consistent and sufficient water supply, making them sensitive to both drought and flooding. Seasonal water scarcity, declining groundwater tables, and competition for irrigation water are widely documented. Conversely, excessive rainfall and waterlogging increase disease incidence. In some regions, water sources are saline or contaminated, undermining crop health and posing food-safety risks. To elaborate, Goyal and Goyal (2022) mentioned that poor quality and insufficient underground water were the primary issues identified by onion cultivators in the Mewat district. Furthermore, climate change exacerbates existing production risks (Shah et al., 2021). Climate change profoundly affects agricultural productivity via several causes, such as elevated temperatures, modified precipitation patterns, and a heightened occurrence of extreme weather events (Annappa et al., 2023). Smallholder farmers with limited adaptive capacity are particularly vulnerable due to insufficient access to irrigation, insurance, and climate-resilient technologies.

Besides that, input and capital constraints highlight obsolete agricultural practices, while shortages of quality seeds, fertilisers, and irrigation supplies hinder farmers' capacity to satisfy market needs (Joshi, 2024). Counterfeit and poor-quality inputs are undermining productivity and farm profitability. Purchasing high-quality inputs will enhance agricultural productivity (Olarewaju, 2025). Moreover, high input costs, combined with limited access to credit, restrict the adoption of improved inputs. Additionally, modern technologies such as drip irrigation, fertigation, mulching, and protected cultivation can significantly improve water-use efficiency and yields. However, high initial startup costs, complexity, lack of knowledge, concerns regarding security and privacy, including employment displacement, limit the

adoption (Ricart, 2025). Smallholders often lack reliable suppliers and after-sales technical support, discouraging long-term uptake. Additionally, vegetable cultivation is highly labour-intensive, particularly during transplanting, weeding, pruning, and harvesting. Labor shortages, driven by rural-to-urban migration and ageing farming populations, increase production costs and reduce the timeliness of operations. The reliance on family labour further limits scalability. Noopur et al. (2023) stated that farmers are encountering challenges related to the cost and availability of field labour.

Market and economic constraints emphasise price volatility, where vegetable markets are characterised by significant price fluctuations due to perishability and seasonal gluts. Sales generally decline due to a shortage of supply, unfulfilled orders, delayed delivery, and diminished market share. At the same time, cost hikes may arise from higher transportation expenses, production rescheduling, suboptimal resource use, and inventory deficits (Mrabet et al., 2025). Fernando et al. (2024) also mentioned that if the market drops drastically, short sellers are condemned for accelerating price decreases by deceptive trading that drives markets below fundamental values. Such volatility reduces incentives for smallholders to invest in productivity-enhancing technologies. Besides that, inadequate market infrastructure, such as poor rural roads, limited cold storage ability, and weak value chain linkages, restricts farmers' ability to reach profitable markets. Goyal and Goyal (2022) disclosed analogous findings in a study examining the principal obstacles in onion production and marketing in Haryana, identifying remote markets, lack of storage facilities, high transportation costs, and low onion prices as primary marketing barriers. Many smallholders depend on intermediaries who capture disproportionate shares of profits. Inconsistent supply and variable product quality hinder access to supermarket and export markets. Additionally, the wholesaler or commission agency capitalises on periods of overstock by purchasing the product at a significantly lower price (Goyal & Goyal, 2022). According to Advertorials (2024) on one website of AgriOrbit, the price of inputs typically rises faster than the price at which the commodity is sold, and a farm's profit margins are squeezed between rapidly rising input costs and market prices that shift or increase more slowly, resulting in a cost-price squeeze effect. In some contexts, government subsidies disproportionately favour staple crops, leaving vegetable growers disadvantaged.

Other than that, the challenges come from knowledge and institutional constraints, where there are knowledge gaps in pest management, nutrient management, and post-harvest handling that constrain productivity and product quality. According to the International Fund for Agriculture Development (IFAD) (2022), extension services in many developing countries are understaffed and underfunded, thus unable to satisfy the more general advisory service needs. Access to private extension services is often limited to wealthier producers. Credit access is a critical enabler for investment in vegetable farming, yet smallholders face substantial barriers due to collateral requirements, high interest rates, and perceptions of high risk (Miller & Jones, 2010). Informal lenders often charge exploitative rates, trapping households in cycles of debt (Uddin & Uddin, 2021). In addition, small and fragmented farm sizes limit economies of scale, mechanisation, and market competitiveness. Insecure land tenure reduces incentives for long-term investments such as soil rehabilitation and irrigation infrastructure (Place, 2009). Policy environments in many countries prioritise staple food crops, leading to underinvestment in horticultural research, infrastructure, and extension services (Pingali, 2012). Weak enforcement of input quality regulations and food-safety standards further undermines vegetable sector growth.

Post-harvest losses in vegetables are among the highest of all crops, ranging between 30 to 40% in many developing countries (Nath et al., 2024). This includes poor harvesting practices, lack of storage facilities, inadequate packaging, and inefficient transportation, which cause losses. Compliance with quality and safety standards, including pesticide residue limits and certification schemes, remains a significant challenge for smallholders. These requirements are often costly and complex, excluding small farmers from high-value domestic and export markets (Reardon et al., 2019). As a result, the absence of strong farmer cooperatives limits collective action in marketing, input procurement, and access to training. This fragmentation weakens farmers' bargaining power and contributes to low returns (Barret et al., 2017).

Lastly, there are socio-gender constraints in the agricultural industry. In many agricultural systems, vegetable production is heavily influenced by traditional gender roles that shape 'who does what' in farming. Women are often responsible for labour-intensive tasks such as planting, weeding, irrigation, and harvesting, while men tend to dominate decision-making processes, land ownership, and marketing (Doss, 2018). Besides, women farmers, who play a central role in horticulture, face constraints in accessing land, credit, training, and market opportunities (Quisumbing et al., 2014). Cultural norms often limit their decision-making power and mobility, reducing their ability to benefit from market-oriented production.

3.0 RESEARCH METHODOLOGY

A qualitative study approach was used to illustrate the difficulties that the farmers encounter in implementing fertigation farming, and convenience sampling was chosen. Convenience sampling refers to the practice where researchers employ a sample that is easily accessible and available to them, making it relevant to nearly any research endeavour (Golzar et al., 2022). By attracting or gathering information from the participants, this kind of sampling helps the researcher, particularly when working with farmers who have more experience in their sector.

A total of 12 participants were selected for this study. In qualitative research, sample size is not determined by statistical power but by the principle of data saturation, where additional participants no longer provide new themes or insights (Guest et al., 2006). The participants in this study represented a relatively homogenous group of smallholder vegetable farmers practicing or familiar with fertigation farming in Sarawak. In such contexts, a sample size of 12 is considered sufficient to capture the diversity of experiences while still enabling an in-depth exploration of individual perspectives. Guest et al. (2006) also assert that the data saturation in homogenous populations may be attained with a minimum of 12 interviews. However, more intricate research designs may require greater sample sizes. Besides, Creswell and Poth (2016) declare that a qualitative study investigating the experiences of caregivers for patients with dementia may encompass in-depth interviews with 10 to 15 participants, since this range can offer sufficient depth for determining key themes. Moreover, the sample size was determined with consideration for practical constraints such as accessibility, time, and resources for fieldwork. Thus, the choice of 12 participants was both methodologically sound and contextually appropriate for achieving the study's objectives.

An open-ended questionnaire was employed to survey the 12 participants, and they were required to provide their responses. Every survey was recorded, which was then transcribed and translated into English for analysis purposes. Additionally, the questions in the survey were created to extract their answers regarding fertigation and their fieldwork experiences in managing this kind of agricultural activity. The questions are unrestricted and cover the topics of why they decided to employ fertigation, their experience utilising fertigation, challenges encountered, and the advantages gained through fertigation. The study and the scheduled survey were explained to the participants over the phone before the survey was conducted. Face-to-face survey and on-site conversations were not possible in 2021 due to the Movement Control Order (MCO) in Sarawak, and the researchers decided to perform an online survey as a result.

Finally, Thematic Analysis (TA) was used in this study for the qualitative data analysis. As stated by Braun and Clarke (2006), Thematic Analysis (TA) is a significant qualitative analysis strategy that may be used as an analytical method in comparison to other qualitative research methods. The researcher conducted the analysis using six phases of thematic analysis. The initial stage is about data interpreting, data transcribing, reading, and re-reading to create the fundamental codes. The second stage involves establishing the basic codes that were used to code and compile the data systematically with essential and intriguing features. The third phase is the selection of the theme, which originates from the data gathered and compiled. The fourth phase is reviewing the themes to determine their relevance to the extracted code and create a thematic map. Phase five involves naming the themes, and the final phase, phase six, consists of creating the report or analysis that addresses the research topics posed at the beginning of the study.

4.0 RESULTS AND DISCUSSIONS

This part delineates the findings pertinent to the initial research objective, which seeks to investigate the obstacles encountered by farmers in Sarawak in the adoption and management of fertigation farming technology. The thematic analysis reveals several significant topics from the data that illustrate the practical and structural obstacles impeding the proper application of fertigation in rural regions. The identified constraints encompass pest and disease, restricted material availability, elevated startup and material expenses, and uncertain access to agricultural marketing channels. These themes offer critical insights into the daily challenges faced by fertigation farmers and underscore the necessity for supportive interventions to enhance the accessibility and sustainability of the technique. The results in this chapter are structured around the principal themes discovered, each substantiated by direct participant responses and contextualised within the overarching framework of agricultural growth in Sarawak.

4.1 Theme 1: Pest and Disease

One participant mentioned that he encountered attacks from pests and diseases that became resistant to the crops that he planted.

"The disease and insects that become resistant. The diseases will increase and spread rapidly since we only focus on a single type of crop. The diseases that concern us are either it is insects or fungi. If there are fungal diseases, numerous insects, the insects become resistant to the crop, and then the availability of our products will drop."

(Participant 2)

Besides, Participant 8 stated that his crops were attacked by pests such as caterpillars that destroyed the leaves of the crops.

"Attack from insects. It is easy too, especially in the beginning, the first month to the third month, the ginger was attacked by caterpillars, which damaged the leaves until they eventually destroyed the leaves."

(Participant 8)

One participant highlighted that even though they have a greenhouse, the pests and diseases are still present and attack the crops and the rhizome itself.

"Challenges in terms of diseases and pests do exist even though we have a greenhouse system. So, the pests that always attack my ginger are Thrips and Aphids. These pests often damage my ginger leaves. As for diseases, ginger plague, leaf spot, leaf blight, and soft rot. The ginger part, which we call rhizome, is also attacked by these diseases."

(Participant 12)

The majority of participants admitted that their most significant challenges were the attacks from pests and diseases. The pest and disease attacks could all be attributed to pathogenic bacteria, the increased risk of fungal diseases, stress vulnerabilities and nutrient imbalances, pest infestation and insect vectors, water quality and contamination, root damage and pest entry, algal growth, increased fungicide use, and environmental conditions. The causes of these events might be natural or human-made, and they frequently connect, making the pests and diseases even worse. Spence et al. (2020) concurred that the risk caused by invasive plant pests and diseases is significant and continuously increasing due to rising globalisation and environmental modifications.

Besides, climate change can also contribute to pests and diseases attack. Doody (2020) stated that with the growing global trade, climate change is one of the factors contributing to the transmission of pests and diseases, in which the size, survival rate, geographic spread of insect populations, as well as the severity, progression, and geographic dissemination of diseases can all be impacted by climate change. Apart from

that, these pests and diseases may also be caused by crop types and varieties, soil nutritional status and fertility rates, poor agricultural practices, poor pest and disease management, pest and disease migration, degradation of biodiversity, as well as economic constraints and financial status. According to Food and Organisation of United Nation (FAO) (2001), pests and diseases have posed a hazard to farmers ever since farming began. As a result, the damage can have an adverse effect on the economy through the loss of output, farmers' income, and assets.

4.2 Theme 2: Availability of Materials

One participant said that the reason why fertigation is left behind in their area is that they faced challenges with the availability of materials in the area.

"The challenge that we face here is actually fertigation, perhaps getting the materials for farming, also one of the reasons why fertigation is left behind in my area. That is the main challenge."

(Participant 1)

One participant stated that they must travel to another city to look for the incomplete materials.

"Difficulty getting materials for fertigation? Yes, my farm area is difficult because it is not sold here. My farm is quite far from the city centre. I have to go downtown to buy the materials."

(Participant 3)

Participant 5 mentioned that their farm is far from the city, and the store is not accessible for them to purchase the equipment and materials. Thus, he needs to travel to another city to purchase the materials, and the cost of transportation needs to be included in the expenses.

"Yes, exactly. It is hard to find the materials because our area is very far from Kanowit and Sibu. I can say that in between Kapit and Kanowit. There is no store at all to buy the materials, even at Kanowit. So, we need to go to the nearest city, which is Sibu to buy the materials. That can be one of the problems where we need to include the transportation cost in it."

(Participant 5)

The second theme emphasised that the availability of materials is also one of the challenges for farmers in the rural area of Sarawak, which poses several issues, primarily due to factors such as infrastructure, accessibility, and financial limitations. Tengku Ahmad and Suntharalingam (2009) agreed that the lack of land, labour, inputs, and capital has led to structural and supply-side issues for the agro-food industry. This issue might lead to an increase in fertiliser prices in the market. As mentioned by two studies by Lahmiri (2017) and Chojnacka et al. (2023), due to a shortage of raw materials, fertiliser prices have skyrocketed during the past two years. Smallholder farmers in the rural areas of Sarawak find it challenging to purchase fertiliser, irrigation pipes, pumps, and other necessary equipment since they are not easily found in local stores, including shipping supplies from urban areas which might be expensive.

The full range of materials required for fertigation systems, especially for more advanced or modern fertigation technologies, may not be carried by local agricultural vendors in many rural regions. The timely application of fertigation procedures may be further hampered because of delays or restricted access to the required components, forcing farmers to either forgo or wait for the delivery from outside suppliers or urban areas. In addition, Gaal (2017) mentioned that inadequate roads and poor road access increase transportation costs, limit access to high-quality inputs, and restrict local markets' usage to product sales, consumer goods purchases, and off-farm work options.

4.3 Theme 3: Startup Cost

One participant agreed that the startup cost for constructing fertigation was very high and tough in the beginning.

"Therefore, it appears that venturing into this fertigation farming is not detrimental despite the initial large expenditures of capital; from the start, the beginning was so tough."

(Participant 1)

Besides that, Participant 3 explained that he had problems with the investment because the fertigation system requires a significant initial investment.

"However, in terms of getting finance, the main problems in fertigation are the investment for setting up the system because it requires a big investment. If we want to do something, you want to do a plot or fertigation."

(Participant 3)

Participant 9 indicated that he did not have enough budget at first, as the startup cost of fertigation was high.

"Yes, regarding that. At first, it was difficult because we lacked the budget to build this fertigation system. After all, it costs quite a lot."

(Participant 9)

The third theme highlighted that the startup cost of fertigation seems to pose another significant obstacle for farmers, particularly smallholders, in shifting to smart farming. Capital is an essential element for the daily operations of a business and for funding its future expansion (Hargrave, 2025). One document from Masterclass's website mentioned that a common definition of capital includes money and other assets, including investments, real estate, financial securities, and intellectual property (MasterClass, 2021). Lazim et al. (2020) mentioned that substantial financial commitment is necessary to execute new technologies, such as the Industrial Revolution 4.0 (IR4.0), encompassing both the initial costs for developing a modular framework and the transformative expenses required for technology adaptation.

Many Sarawakian smallholder farmers may have limited funds, making it challenging to make investments in such technologies, even though they are accessible. The lack of capital impacts both production and the quality of agricultural products. Emon (2023) indicates that adopting modern technologies in agriculture might be expensive, with high startup costs for modern technology, software, and networking infrastructure being the major obstacles for farmers, especially smallholder farmers. Ali et al. (2025) also point out that the upfront investment in automated systems, controllers, and sensors is potentially absurd due to the costs related to software, hardware, installation, and daily maintenance. As the public is aware, fertigation requires specialised equipment such as fertigation tanks, mixing units, drip irrigation systems, and high-quality fertilisers. In rural areas, these materials could undergo price hikes partially due to the limited supplies or availability, longer supply chains, or the shortages of competitive suppliers.

4.4 Theme 4: Market Fluctuations

One participant had issues with market prices. This might be due to the high cost of bringing products to the market, and the farmers are forced to sell their products at a cheaper price.

"The market price is also a challenge for me because the desire to sell the product is slightly higher than the market price, but when you look back, people are more inclined to buy cheaper goods. This makes it difficult for me to sell if the price we set is more expensive than the market price."

(Participant 3)

Participant 12 acknowledged that he must agree to accept the lower price that the buyers offer due to a lack of negotiating power.

"It is quite difficult for me to follow the market price because we cannot sell it at a higher price than the current market price. For example, I sell it to the supermarkets. The supermarket will buy at the price they will offer. So, we have to accept whatever price they offer."

(Participant 12)

One participant declared that they have to compete with imported products, and the potential to sell their products at a competitive price is seriously threatened by the cheaper products that are imported from other countries.

"We know that sometimes there is a competition from outside because now the problem is, imported products from Thailand and Vietnam, as well as those that have been smuggled across the border. One is imported products from Vietnam and Thailand. They sometimes use containers, okay. That will lower the local price."

(Participant 4)

Besides that, the fourth theme underlines that the fertigation farmers in Sarawak rural areas face difficulties regarding product price or market price. Both direct and indirect challenges may arise and affect their entire profitability and productivity. The currency exchange rates, shifts in global supply chains, and the cost of raw materials can all affect market price fluctuations. Fertigation farmers find it challenging to plan for profitability since any fluctuations in prices have a direct influence on their production expenses. As mentioned by the Food and Agriculture Organisation of the United Nations (FAO) (2022), the market pricing for their products, which are either sold at the market where the sale is directly done through a middleman, or from their farm (the farm gate), is the primary source of income for them. Before this, the dominance of middlemen made it harder to obtain revenue. The farmers obtain far less return than what consumers pay at marketplaces since they do not have direct access to markets. Koshy et al. (2021) stated that Food Supply Chains (FSCs) are frequently criticised for their exploitative middlemen and retail chains, which control markets and marginalise farmers, small-scale retailers, and consumers.

Another issue regarding this product price or market price is that farmers frequently have little negotiating power and only get a small percentage of the final retail price. The farmers must find a buyer who will be willing to pay them a fair price for their products, while also making sure that they do not market their product at a price that is either too low or too high compared to the current market prices. Farmers from rural areas are forced to promote their products at a lower rate or give them away for free because they are unable to attract buyers. Chen et al. (2017) noted that farmers frequently market their products at unfairly low rates to avoid spoilage. If their product costs more than the going rate, the farmers need to reduce the price because some consumers will opt to purchase the less expensive one. So, the farmers must accept any price that the consumer offers. Solon (2013) also mentioned that farmers do not always receive the best bargain since the prices are unclear.

Besides that, cheaper imported products frequently pose a serious threat to rural farmers' ability to sell their products at competitive prices. According to one report by Amir (2025), local growers are unable to compete with low-cost imported products from Vietnam, Thailand, and China. As a result, some farms responded by letting crops rot, claiming that agricultural programmes are useless and that there is a pressing need for better support. Palansamy (2022) further noted that local growers were not turning a significant profit at the current price cap of RM8.90 per Kilogram (Kg) for dressed chicken, despite the government's 60-cent subsidy. Local farmers may find it more challenging to compete with imported goods because of lower prices brought about by subsidies in the country of origin or economies of scale.

4.5 Theme 5: Material Costs

One participant claimed that he had trouble with the cost of materials because it keeps increasing year by year. Due to this, the participants are severely impacted financially, particularly smallholder farmers who struggle to cover these costs as they need to follow the current market price to sell their product.

"The material is a bit expensive. Now, the price of fertilisers, chemicals, and other materials that are necessary for planting is rising in the market. That is why I told you if I want to sell my product, it is a bit challenging because we need to follow the current market price. If we set the price low, our profit will decrease."

(Participant 9)

One participant stated that the shipping cost from Peninsular Malaysia was higher than the price of fertiliser because Sarawak is located on the island of Borneo, and it contains many isolated communities that are difficult to reach by road, particularly in the interior area.

"Previously, I ordered from Peninsular Malaysia, but the cost was too high. I can say that if I use Poslaju Malaysia, the price of the shipping is higher than the fertiliser itself."

(Participant 1)

Lastly, besides the increasing price of materials, one participant mentioned that they need to buy the essential materials for their fertigation system in another area or city. They also said that the transportation cost was included in their expenses.

"The cost of the materials? Okay, it's a bit expensive for me because of the cost of transportation also I have to add in the cost of fertigation materials because in my area, it is difficult to get a complete material plus my farm is far from the city centre. Small grocery stores sell it, but not fully stocked. So, because of that, I have to go to another city to find other materials that are not available at the store."

(Participant 12)

The fifth theme clarifies that the cost of materials also brought challenges to the fertigation farmers in rural areas of Sarawak. As mentioned before, agriculture plays an integral part in the global economy, producing food, basic supplies, and fibre that human beings need in their daily lives. This is agreed upon by Dhillon and Moncur (2023), who stated that smallholder farmers are essential to the financial development and political stability of rural communities, as they create products that support locals' nutrition, health, and food security. In agriculture, material costs are the expenses related to the inputs that are necessary for the agricultural activities, which involve fuels, plants, and animals, protecting products, devaluation of fixed assets (structures, agrarian machinery, buildings, etc.), construction expenses, and biological costs for bedding, feeds, seeds, biological supplies, fertilisers, and the total amount of devaluation of biological assets (Alkarawy & Al-Ssadi, 2023). Similarly, the cost of materials needed for agriculture has increased due to stricter environmental regulations and the limited supply of certain chemicals. As indicated by Verma et al. (2024), the cost of producing and growing crops has increased for farmers for several reasons, including the fact that input costs, such as fertiliser, pesticide, and seed, can change depending on the demand, supply, and availability in the market.

The rising cost of materials is a significant concern for farmers as it impacts their overall profitability, sustainability, and productivity. As stated by Saiin et al. (2024) on chilli production under an open field fertigation system, the rising costs of chilli production necessitate that growers reduce expenditures to maintain profitability. Additionally, the study by Sanchi et al. (2022) discussed the price fluctuations of agricultural inputs brought on by changes in market prices, where marketers have a significant effect on agricultural activity. Furthermore, Hulme (2011) also mentioned that the cost of agricultural products, especially fertilisers, may change annually. He added that a few variables, including the global marketplaces, the location, politics, logistics, transportation, and energy costs, ultimately alter the cost of materials and their accessibility, which is often used in greenhouses and nurseries.

In addition, another issue regarding these challenges that the participant mentioned was the shipping cost. Due to infrastructure, geographic, and logistical issues, farmers find it difficult to obtain materials in the rural areas because of limited transportation. Sarawak is located on the Island of Borneo and has numerous isolated villages and communities that are difficult to travel by road, especially in rural areas. A few decades ago, some remote areas were only reachable by river or air. This issue forced the farmers in rural areas to travel to another city to purchase the materials, and some even order from another country. These become an issue for them because the transportation and shipping costs are high, and these costs need to be added to the input cost or material cost. Additionally, Olumba and Onunka (2020) discovered that banana and plantain farmers faced significant challenges, including the lack of roads, which prevents vehicles from travelling, high transportation expenses, and inadequate road infrastructure, which raises operational costs. On the other hand, research conducted by Savic et al. (2020) indicated that internal issues, including inefficient use of transportation, organisation, poor planning, and management of transportation activities, contribute to the progressive increase in transportation costs. To that, Jefrin and Saili (2025) added that the high cost of transportation is a significant factor in reducing revenues and raising entire production costs, especially for smallholder farmers.

4.6 Theme 6: Climate Change

One participant mentioned that he encountered climate change as a challenge in employing fertigation.

"Firstly, end of the year, our weather here always rains every day. Then, when it rains, the workers are unable to do their work. Second, the soil will be hard because it already, how to say? When it gets the water, the soil becomes difficult to break, which means not easy for planting."

(Participant 6)

Participant 8 stated that he employed an open-system fertigation and that there was no greenhouse to protect the crops.

"Yes, the weather is also challenging because my system is an open fertigation. I do not have a greenhouse, so I only use sun shade netting around my fertigation. The problem is when it rains too much, the crops will easily be exposed to some disease and pests, and during the dry season, the soil will dry up faster than usual."

(Participant 8)

Lastly, the unstable climate change in Malaysia posed a challenge to this participant, even though he had a greenhouse system on his farm.

"Yes, despite the existence of this greenhouse system, climate change is also a challenge for me because we know that the climate in Malaysia is unstable. If it rains so much, the plants get less sunlight to help their growth, while if it is a dry season, there is dryness in our crop medium. I am thankful that this automatic fertigation system can help me simplify the work of watering and fertilising."

(Participant 12)

The sixth theme reveals that the participants experienced challenges due to climate change, especially for participants who adopt an open-field fertigation system. A weather occurrence known as "climate change" is one that abruptly shifts and has long-term consequences, where consequences like global warming lead to an increase in sea levels, and the rise in severe weather events like floods and drought (Hassan et al., 2023). Even though fertigation is designed to optimise the delivery of nutrients and water, unpredictable precipitation patterns might affect the amount of water and how often it is used for irrigation. During the period of excessive rainfall, fertigation systems may become overloaded, leading to nutrient waste and overflow. In contrast, during the drought season, fertigation might not be effective because there will be less water supply. Additionally, the humid conditions, frequent rains of Sarawak's tropical climate, and the topographical features of Sarawak, such as the remote areas for farming and rugged terrain, can

make fertigation farming difficult to establish and operate. As for farmers in these regions, the process of transporting supplies, maintaining equipment, and ensuring that water and fertiliser are applied regularly may also be challenging.

According to a report in Sarawak Focus (2023), one of the primary consequences of Sarawak's changing climate shift was the increase in temperatures, where the regions of flora and fauna may experience heatstroke due to the rise of temperature. This may affect their rates of growth and survival, along with prolonged droughts and heavier precipitation during rainy periods, which can be harmful to agricultural activities, since alterations in patterns of rainfall is also a big issue. Besides that, the damage to crops due to the floods or the crops receiving insufficient supply of water during the dry seasons can lead to shortages of food. Rajendran (2025) stated the recent flooding that occurred in December 2024 in Malaysia had destroyed approximately 100 hectares of agricultural land in Melaka, Perak, Johor, and Kelantan, causing the prices of vegetables to soar by 50% to 80. Also, the severe supply scarcity brought on by the flooding resulted in a further increase in prices. Prior to this issue, some participants also stated that climate change can cause pest and disease attacks.

Climate change profoundly affects pest and disease outbreaks by modifying climatic circumstances that promote the development, survival, and dissemination of pathogens and insect pests, while also undermining natural defences against pests. This is agreed by Alfizar and Nasution (2024), who mentioned that the frequency, dispersion, and severity of pests and diseases can all be impacted by climate change, leading to outbreaks in agricultural and natural systems. Warm conditions hasten the reproduction and growth of pests and diseases, increase populations, and shorten life cycles (Bebber & Gurr, 2015). Furthermore, modified weather patterns that foster the establishment of vectors and pathogens influence disease transmission and plant vulnerability (Chakraborty & Newton, 2011).

4.7 Theme 7: Lack of knowledge

One participant acknowledged that in the beginning, his knowledge about fertigation farming was empty.

"Yes, I admit that I have a lack of knowledge in this field. To do this fertigation, very deep knowledge related to this fertigation is very important. We have to know the pros and cons of it, the diseases and insects that are present, the quantity of fertiliser and water, and many other things."

(Participant 3)

Other than that, one participant stated that he also sought help from the Agricultural Department to assist him in handling the fertigation system.

"Oh, absolutely. I have a lack of knowledge about this fertigation, from zero. I'm just asking the Department of Agriculture. Yes, because we have one head of Department that assists us."

(Participant 6)

Another participant indicated that he had little knowledge about fertigation and also intended to learn it from social media platforms such as Facebook, YouTube, and other useful platforms.

"Absolutely no. We do not know at all in the beginning. That is why we continue to update everything with our friends who are successful in this fertigation. Besides, my husband and I tried our best to study and learn from other platforms such as Facebook, YouTube, and so on. There are so many useful videos that we can watch."

(Participant 5)

Referring to this theme, the participants acknowledged that they lacked knowledge and training before implementing the fertigation farming. One major obstacle impeding the implementation of technologies in agriculture is farmers' lack of knowledge and expertise in handling new technologies (Quy et al., 2022).

Abang Ahmad et al. (2024) also mentioned that proficiency in knowledge and technical expertise is essential for managing technologies, and it is particularly beneficial when farmers perform in both agricultural and information and communication technology (ICT). Farmers must possess a particular amount of experience and knowledge to effectively develop, install, and maintain the fertigation technology. According to the statement from Jiva's Team (2023) website, these agricultural communities' potential to grow and innovate is hampered by the lack of knowledge accessibility, which recurrently poses challenges.

There is no doubt that in-depth expertise and abilities are needed to handle this fertigation, such as soil nutrients and water level monitoring, handling fertigation operations, and calibrating technology, where most of the smallholder farmers in rural areas of Sarawak lack the knowledge, expertise, and training required to perform this fertigation. As indicated by Omar et al. (2024), farmers in developing nations usually lack formal knowledge and practical skills. In addition, when farmers in remote areas are not carefully assisted, they may misuse this modern technology, which could lead to system failures, low crop production, and unbalanced nutrients. Musa and Ab Aziz (2022) added that an absence of adequate education will further exacerbate farmers' deficiency in marketing skills, leading to a lack of marketing competence.

Farmers need to undergo sufficient training on how to integrate fertigation farming with other types of farming practices, such as scheduling irrigation and managing pests, to improve their operational skills. Unfortunately, the availability of agricultural education and extension programmes is usually restricted, which limits access to education and hinders the widespread usage of fertigation farming activities. Singh and Mishra (2024) outlined that agricultural extension significantly contributes to the effective execution of programmes about agriculture and rural development. Observers express concern that public extension fails to address these challenges effectively, does so insufficiently, and is not consistently relevant.

4.8 Theme 8: Agricultural Marketing

One participant mentioned that his market area is small, as many others in his area grow the same produce; therefore, he needed to market his produce outside of town.

"The market is also quite limited in my area because some residents here can grow their chilies for their use, and some prefer to buy at the supermarket. So, I have to market it outside my area."

(Participant 3)

Additionally, one participant acknowledged that he cannot market his product to a supermarket because the supermarket only buys his product in large quantities.

"Yes, it is a problem also, as there was a barrier in marketing our product because we cannot supply it to the supermarket or market. You need to prepare a large quantity before selling them to the supermarket. That is the problem because I only have a small-scale fertigation, which I mentioned to you before, only 550 polybags available in my garden."

(Participant 8)

Lastly, one participant mentioned that the crops he planted using a fertigation system were only enough to meet the supply and demand in his area. Moreover, the sale of crops in his area also faces stiff competition as many other farmers market the same produce.

"For the market, I have not been able to market to other Districts because it is just enough for usage in my area. But it is quite difficult because we have to compete for the market with other farmers who planted ginger to sell the crops."

(Participant 12)

The last theme, theme eight, addresses the challenges of agricultural marketing faced by the participants. The concepts of "agriculture" and "marketing" were merged to create the term "Agricultural Marketing" (Jeyaramya, 2022). As stated by Sarap and Nemade (2021), agriculture is defined as the growing or raising of crops and livestock. In contrast, marketing encompasses a variety of operations that include moving the goods from the places where they are grown to the areas where they are consumed. Agricultural marketing includes activities such as identifying potential consumers, negotiating prices, transporting merchandise, and gathering feedback on the products' quality.

Subjected to this theme, some participants noted that they have limited market access in rural areas, which frequently compels them to convey products over extensive distances, leading to elevated costs, deterioration, and diminished income. Most rural farming areas in Sarawak lack centralised collection or distribution channels, a poor road network, limited logistics facilities, and are geographically isolated. One document from the Agriculture Institute website that covers the topic of Challenges in Agricultural Marketing: Issues and Solutions as mentioned by Agripreneurship (2024), said that inadequate rural connectivity results in farmers frequently encountering difficulties in transporting their produce from farms to the marketplace in a cost-effective manner. Moreover, the participants acknowledged that finding any buyers or consumers during the recent COVID-19 pandemic was challenging. This was proven by Musa and Ab Aziz (2022), where engaging consumers proved to be one of the most difficult challenges of operating a business due to the COVID-19 outbreak.

Besides that, some participants also noted that they faced significant difficulty, where they were unable to satisfy the substantial volume demands of wholesalers, supermarkets, or food processors. In addition, the demand for food is escalating due to population growth and increasing caloric intake, which is projected to rise by 70% to 100% by the year 2050 (Musa & Ab Aziz, 2022). Large-scale merchants frequently require regular, mass quantities of consistent produce, a demand that smallholder farmers find challenging to provide due to constraints in land, resources, and infrastructure. This scenario highlights a disparity between market demand and farmers' output capabilities, particularly for those employing capital-intensive methods such as fertigation, which remain limited by land area. Consequently, these farmers are frequently marginalised from profitable markets and are compelled to sell at local wet markets or rely on intermediaries who provide lower prices. According to a report by Lorna (2024) in Sarawak Tribune, the lack of quantity and consistent supply prevents most rural farmers from reaching institutional purchasers.

5.0 CONCLUSION AND RECOMMENDATION

Although fertigation is an effective way to boost agricultural and crop productivity among farmers in rural Sarawak, adoption is hindered by multiple challenges. These include pests and diseases, limited availability of materials, high startup costs, market fluctuations, rising material costs, climate change, lack of technical knowledge, and marketing constraints, all of which reduce the efficiency and sustainability of fertigation farming. Addressing these issues will require a comprehensive strategy involving government support, improved infrastructure, targeted technical training, and the promotion of sustainable farming practices. By overcoming these barriers, smallholder farmers in rural Sarawak may be able to leverage fertigation , ultimately enhancing food security and contributing to regional economic growth.

The novelty of this study lies in its first-hand qualitative documentation of the live experiences and specific challenges faced by smallholder fertigation farmers in Sarawak, integrating technical, economic, environmental, and institutional barriers into a unified framework. This study is the first, to the best of current knowledge, to present these diverse challenges collectively within the Sarawak context, providing policymakers and practitioners with contextualised evidence to inform intervention planning.

However, this study is limited by its small sample size and focuses on selected rural districts, which may not represent all fertigation farmers in Malaysia. Future research should expand to other regions, incorporate quantitative analyses of economic viability, and evaluate targeted interventions to support widespread and sustainable adoption of fertigation systems.

6.0 CONTRIBUTION OF AUTHORS

The authors confirm the equal contribution to this paper and approve the final version.

7.0 FUNDING

This work received no specific grant from any funding agency.

8.0 CONFLICT OF INTEREST STATEMENT

The authors agreed that this research was conducted in the absence of any self-benefits, commercial or financial conflicts, and declared the absence of conflicting interests with the funders.

9.0 ACKNOWLEDGEMENT

The author would like to thank Associate Professor Ts. Dr. Abdul Rahman Bin Saili as the primary supervisor for the exceptional guidance, unwavering support, and insightful feedback throughout this research. The authors also wish to thank the reviewers and editors for their valuable insights to improve this paper, and the participants who took part in the research.

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