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REVIEW

Oil Palm in the Face of Climate Change: The Role of Extension Services in Malaysia

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ABSTRACT

Oil palm cultivation significantly contributes to Malaysia's economy by generating income, creating employment, and alleviating poverty through the sale of palm oil products. As the world's second-largest exporter of palm oil, Malaysia plays a vital role in global markets. However, oil palm production faces climatic, edaphic, and socio-economic challenges, including poor yields, rising palm oil prices, increasing temperatures, water stress, and disease outbreaks. Among these, climate-related issues are the most persistent, posing significant risks to cultivation. This review assessed the state of extension services in Malaysia's oil palm sector, highlighting challenges faced by extension agents and exploring innovative methods to enhance service delivery. Findings indicate that excessive heat induces water stress, reducing the metabolic efficiency of oil palms and lowering fresh fruit bunch (FFB) yields. Additionally, heavy rainfall delays harvesting and causes FFB rotting, further impacting productivity. To address climate challenges and ensure sustainable cultivation, Malaysia has implemented various programs, with extension services playing a crucial role. These services provide essential information, innovations, and interventions to oil palm growers, enhancing their resilience. They also facilitate connections between stakeholders, including government and non-governmental organizations. This study recommends strengthening extension services to support climate adaptation, developing new policies and guidelines for plantations, training more personnel, promoting

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partnerships, increasing resource allocation, and promoting stakeholder collaboration. Therefore, implementing these strategies, Malaysia can enhance the sustainability of its oil palm sector while mitigating climate-related risks.
Keywords: Climate Change; Extension Services; Oil Palm; Growers; Malaysia

1. Introduction

The oil palm (*Elaeis guineensis*), the world premier cultivated palm oil species, originates in equatorial Africa; it is an indigenous plant in areas that stretch from Guinea to Angola [1–4]. The native range of oil palm is disputed [5]. The plant is an immensely productive and efficient tropical crop, it is easy to establish, requires low capital expenditure, and has a high output; it is also extremely profitable as a cash crop [2]. Oil palm cultivation is predominant in equatorial lowlands, covering around 18.1 million hectares in 43 countries. Indonesia (7.1 million hectares) and Malaysia (5.87 million hectares) collectively account for about 85% of the world's crude palm oil production [2]. In the oil palm industry, the most crucial countries are Indonesia, Malaysia, Nigeria, the Democratic Republic of the Congo, the Ivory Coast, Brazil, Colombia, Costa Rica, and Ecuador [1, 2].

Oil palm flourishes in humid climates with nighttime rain and sunny days, needing at least 2,000 mm of rainfall annually (around 167 mm per month) and over 2000 hours of sunshine per year or a minimum of 16 MJ m^{-1} d^{-1} [6, 7]. For optimum oil palm bunch production, temperatures between 22 °C to 24 °C and 29 °C and 33 °C are ideal [1]. Relative humidity should be greater than 85% [7]. The plant can thrive in variety of soils, with pH at 4–8 with abundant moisture. When there are faster growing trees nearby, oil palm cannot thrive well, fails to grow in persistently flooded areas, and requires open spaces [2].

The economies of palm oil-producing nations benefit greatly from the exports of palm oil and its derivatives [8]. In 2020, palm oil made up almost 38% of Malaysia's agricultural output and contributed 3% to its GDP [9]. Palm oil is found in various products, including food, cosmetics, cooking ingredients, plastics, chemicals, pharmaceuticals, and biodiesel [10]. Rival [11] and Paterson and Lima [12] observed that climate change will cut back on the areas planted with oil palm, force plantations to move to other areas—with the assumption that problems like loss of biodiversity can be solved—and test the adaptability of growers. Paterson et al. [13, 14] noted that changes in climate will negatively affect oil palm harvests. In general, oil palm cultivation will be adversely affected by biotic factors (such as diseases, pests, pollinators, and associativity) and abiotic factors (including rainfall, temperature, carbon dioxide levels, and soil salinity) [15]. The effects of climate change on oil palm have been demonstrated through changes in rainfall intensity, as well as the uncertainties in weather patterns. These factors have led to droughts and extreme rainfall events, resulting in flooding and the destruction of oil palm plantations along coastal regions [4]. Climate change and variability affect global oil palm yields, which are greatly influenced by factors such as location, genetics, irrigation, and political commitments [10, 16]. A study conducted by Abubakar et al. [4] demonstrated that technology, genetics, climate, soil conditions, and field management practices—including fertilizer usage, tillage methods, hybrid selection, irrigation management, row spacing, planting date, cultivation depth, and density—are the primary factors influencing oil production on a global scale [4]. Technological advancements in both upstream and downstream processes have significantly contributed to advancements in oil palm production, particularly in Malaysia and Indonesia [17].

Previous reviews have addressed the impact of and adaptation strategies to climate change on oil palm production [4, 10, 12, 16]. Others explore present and future climate suitability for oil palm production [13, 18]. Oil palm sustainability [19–26]. A number of studies have examined the impact of pests and diseases on the production of oil palm [27–33]. Studies have extensively reviewed and analyzed oil palm agronomy, plantation operations, machinery, insect pollination, ecosystem function, climatic requirements, carbon sequestration, and the oil palm industry and value chain [2, 12, 34–37]. In Malaysia, this study was able to identify a single review paper on the role

of social media in oil palm extension services [38]. In response to this gap, this study examines how extension services are contributing to oil palm production in Malaysia under changing climates.

Danso-Abbeam et al. [39] describe agricultural extension as a system that assists farmers in improving farming methods and techniques, increasing production efficiency and income, improving their standard of living, and raising the social and educational standards of farmers through educational procedures. Agricultural extension services offer technical advice to oil palm growers, help them access necessary inputs such as credit for farming, provide training and evaluation of new agricultural technologies on oil palm plantations in close collaboration with growers, facilitate connections to supply chains and markets, convey growers' concerns and problems to decision-makers, and thus contribute to policy formulation [38]. In the context of Malaysia, agricultural extension programs are designed to complement farmers' indigenous knowledge with the most up-to-date information and skills for optimal farm cultivation and management practices [38, 40, 41]. Oil palm productivity increased as a result of the application of technological components such as good agricultural practices learned through the organised extension programs in Malaysia [42]. Farmers' participation would enhance the learning, transfer, and adoption of agricultural technology [38, 40–42]. As a result, effective guidance and advice from extension workers are required so that farmers can properly implement new technology [42].

This review aimed to address the overarching question: How can extension services in the oil palm industry be optimized to support sustainable production, mitigate environmental impacts, and enhance socio-economic outcomes for growers? The objective of this review was to analyze the current status of extension services in oil palm cultivation, identify key challenges and barriers faced by extension agents, and explore innovative strategies for improving service delivery. The identified research gap lies in the limited understanding of the most effective methods for delivering extension services to diverse stakeholders, including smallholder farmers and large-scale plantations, particularly in the context of climate change adaptation and sustainability. This review contributes to the existing literature by providing an indepth analysis of extension services in the oil palm sector, offering insights into the customization of services to suit the needs of different growers, and proposing recommendations for enhancing the effectiveness and impact of extension programs. Additionally, by integrating socio-economic impact assessment, this review aimed to clarify the role of extension services in promoting inclusive growth and poverty reduction in oil palm-growing regions. Also, this review offers valuable insights for policymakers in the oil palm industry. Simultaneously, it enhances understanding of the importance of extension services in oil palm production and climate change adaptation in Malaysia. Moreover, it presents an opportunity for institutions and government agencies to formulate and execute policies that support the role of extension services and enhance yields through the adoption of best practices. Additionally, it sheds light on new opportunities for smallholder farmers to access extension services, adapt production practices, and plan for the future to maximize yields.

2. Climate Change Impact on Oil Palm Production

Higher temperatures cause accelerated evaporation of soil water, resulting in water stress to the palms [1, 5, 7, 15]. Although predictions for Southeast Asia in the year 2100 show that temperatures will become unfavourable for oil palm production [15], although a minimum temperature increase may boost oil palm yield, as seen in the west coast of Sabah [43]. When temperature rises by 1–4 °C the production of oil palm is expected to decline by 10–40% in Malaysia [44]. Similarly, when the temperature rises by 2 °C and rainfall declines by 10%, oil palm yield is expected to decrease by 30% [12]. The El-Nino occurrence in the Pacific Ocean reduces rainfall in Malaysia, exacerbating high evapotranspiration, decreasing the production of male and female flowers, soil dryness, drought conditions, water stress, and resulting in the decline of annual FFB yield [1, 7, 45]. Climate change led to a reduction in production by 26.3%, while drought in Southeast Asia further decreased palm oil production by 10–30% [12]. As a result of La Niña,

warm water and precipitation from the trade winds occur in the western equatorial Pacific. As reported by Albani et al.[46], this phenomenon leads to heavy rainfall in northern Australia and Southeast Asia, including Malaysia, due to cooler surface water in the equatorial Pacific Ocean. The impact of La Niña delays harvesting activities, leading to the rotting of fresh fruit bunches (FFB)[45, 47]. Kamil and Omar[48] observed that "La Nina also affects processes at an earlier growth stage, such as frond production, sex ratio, the extent of floral abortion, the degree of survival of flowers after anthesis and bunch weight". Other climate change effects on the production of oil palm are higher abortion rates, elongated inflorescence, decline in productivity, higher lance leaf number and upper biomass break, dehydration of tissue and cell, poor uptake of nutrients, general metabolism disruptions, and negative influence on photosynthesis[4]. Increase in the prevalence of pest and disease outbreaks is caused by higher temperatures altering the reproductive patterns and life cycles of pests and diseases, impacting pollination and disrupting the normal mechanisms of pollinators like *Elaeidobius kamerunicus*[4, 15].

Effect of Oil Palm Cultivation on Climate Change

The impact of oil palm cultivation, especially the conversion of tropical rainforest into plantations, remains a significant environmental challenge[12]. During the clearing of tropical forests for oil palm plantations in Malaysia and other oil palm producing countries, carbon is released into the atmosphere as carbon dioxide[12], exacerbating global warming, climate change, loss of biodiversity, water shortages, loss of natural vegetation and climate regulation functions[2]. Dislich et al.[2] report that the carbon emissions from forest conversion outweigh the potential carbon sequestration of oil palm, due to fires used for land clearing and greenhouse gas emissions from fallow land and plantation establishment. Other impacts of oil palm expansion include the emission of volatile organic compounds from oil palm plantations, which can reduce air quality, especially during El-Nino years. Additionally, forest fires result in the emission of CO_2, volatile organic compound emissions, particulate matter, and aerosols, leading to the modification of micro-climate and solar radiation[2]. As a result of fertilizers being applied in plantations, oil palm trees emit more N_2O into the atmosphere than forests, while fires emit black carbon, contributing to global warming[2, 50, 51]. Between 2000 and 2019, the oil palm area in Malaysia grew from 2.5 million ha to 5.9 million ha[52]. Jaafar et al.[53] observed that from 1990 to 2020, there was a 12.6% decrease in forest cover and a 16.3% decline in Sarawak, along with a 20.5% decrease in peatland area and a 19.1% decline in Sabah. The decrease in forest cover leads to the release of 0.01577 and 0.00086 Gt CO_2-C yr^{-1} [53]. **Table 1** presents some related studies to oil palm extension services and climate change.

Table 1. Summary of some related studies to oil palm extension services and climate change.

Author and Year	Title of the Article	Research Objectives	Significant Findings
Abubakar et al.[10]	Impacts of and adaptation to climate change on the oil palm in Malaysia: a systematic review	"To examine the impact of climate change on oil palm production and identify the farmers' adaptation strategies to the impacts of climate change in Malaysia"	The findings showed that increasing temperature and variability in rainfall, along with other climate extremes, have a significant impact on oil production, leading to water stress and infestation of pests and diseases.
Abubakar et al.[16]	Nexus between climate change and oil palm production in Malaysia: a review	"To examine the impacts of climate change on oil palm production in Malaysia and the various adaptation strategies to adapt to the impacts of climate change"	A shifting climate impacts the intensity and duration of rainfall, subsequently influencing the quality of crude palm oil and the yield of oil palm fresh fruit bunches (FFB).
Shah et al.[39]	Roles of extension agents towards agricultural practice in Malaysia	"To investigate the level of roles played by extension agents in Malaysia"	The study concludes that extension agents have a high level of engagement with farmers by communicating new innovations and assisting them in decision making.

Table 1. *Cont.*

Author and Year	Title of the Article	Research Objectives	Significant Findings
Awang et al. [42]	Agriculture technology transfer and productivity of independent oil palm smallholders	"To investigate the extent to which technology transfer aid in sustainable agricultural production among smallholders"	The results of the study confirmed that technology transfer is effective in agriculture practices and enhance productivity.
Ibitoye et al. [54]	Factors affecting oil palm production in Ondo State of Nigeria	"To examine factors affecting oil palm production in Ondo State, Nigeria, due to crude oil discovery and civil war impacts"	Adulterated seedlings (13.3%) and premature transplanting (53.3%) hinder yields; education and training frequency significantly influence oil palm production success.
Rahman et al. [55]	Social media literacy among oil palm smallholders in East Malaysia and association with oil palm integration practices	"To investigates social media literacy among oil palm smallholders in East Malaysia and the association	Younger oil palm smallholders with higher education levels exhibited significantly higher social media literacy. As a result, online extension services can be used to adopt a variety of ideas.
Saad and Salman [56]	Acceptance of oil palm innovation among smallholder farmers in East Malaysia	"To examine the influence of innovation, knowledge, social system and communication channels towards acceptance of agricultural innovation among oil palm smallholders"	Smallholders in the East Coast of Malaysia accepted oil palm innovation based on the characteristics of innovation and communication channels
Tan et al. [57]	The role of social media applications in palm oil extension services in Malaysia	"To examine the role of information and communication technology as tool for conveying knowledge to oil palm smallholders"	Based on the study results, social media applications can be used to improve technology applications and palm oil information.
Basaruddin et al. [58]	Acceptance level of independent oil palm smallholders in Malaysia towards extension services	"To determine the perception and attitude of independent oil palm smallholders toward the extension service activities by extension group"	It is concluded from the study that oil palm smallholders perceive, understand, and accept extension services in a positive manner.
Nabara and Norsida [59]	The role of extension in activity-based adaptation strategies towards climate impact among oil palm smallholders in Malaysia: a systematic review	"To investigate the role of agricultural extension in activity-based adaptation strategies among oil palm smallholders in Malaysia".	Educating farmers by encouraging them to learn, adopt, and communicate new technologies is an important function of extension services.

3. Oil Palm Extension Services Program

In its effort for sustainable oil palm production, in 2012 MPOB design an extension scheme known as Tunjuk Ajar dan Nashit Sawit (TUNAS) in order to provide smallholder oil palm growers with extension services [60]. MPOB empowered independent oil palm growers to achieve a yield of 22 tonnes per hectare by 2020 through an oil palm guidance and extension program [42]. From 2011 to 2013, the MPOB spent approximately RM 902 million intended to empower oil palm smallholders via an extension program [42]. As they significantly contribute to Malaysia's GDP [61]. This program involved 68,314 independent smallholders. A total of 1,189 technical consultations and 16,898 farm visits were conducted in various regions of Malaysia [42]. A study among organized smallholders in Terengganu showed that involvement in the oil palm smallholders' scheme positively affected their lives by boosting income and consequently improving their standard of living [21, 62]. Independent smallholders were educated in the sustainable intensification of existing plantations through the oil palm guidance and extension program [42]. To maximise their productivity, most oil palm growers required ecological and agronomics knowledge of the oil palm plantation system [42]. Through extension agents, plantations quickly adopted new technologies, especially in the management and fertiliser application [63]. Larger oil palm companies frequently claim to practise corporate social responsibility by participating in many community outreach and education programs [21]. It is difficult to pinpoint or track the effects of these programs on local communities due to the lack of available data [21]. The possible future implementation of precision agriculture will increasingly optimise fertiliser application, al-

lowing for the realisation of site yield potential [63]. Past national agricultural policies drove the agricultural sector to achieve a growth of 3.2% annually from 1985–1995 [64]. The oil palm sector on its own attained a growth rate of 19.1% in 2000, 22.5% in 2005, and 25.0% in 2010 [64].

3.1. Approaches to Oil Palm Extension Services in Malaysia

Extension approaches in the oil palm sector varies, depending on the stage of oil palm development [65]. Kapia-Mendano [65] and Famuyiwa et al. [66] stressed the significance of the extension approach, which encapsulates the philosophy of the system, dictating the structure, programs, methods, and technology to be employed. As per Musa et al. [67], the oil palm sector in Malaysia employs a range of extension service methods, encompassing the general agricultural extension approach, commodity-specific approaches, the training and visit model, participatory agricultural extension methods, project-based approaches, cost-sharing mechanisms, and educational and institutional strategies.

3.2. Extension Agents Training and Oil Palm Production in Malaysia

In recent years, various challenges have arisen in the oil palm industry, particularly concerning climate change. These issues demand comprehensive attention and thorough analysis to ensure sustainable oil palm production [10]. Alotaibi et al. [68] observed that training of extension agents (formal and informal) is key to successful agricultural production. Pakri et al. [69] contended that the efficacy of extension services heavily depended on proficient extension agents who comprehended their roles and demonstrated competence in executing them. These agents bore the responsibility of conveying information to farmers throughout the entire extension process. The purpose of training extension agents is to expose them to either old or new technologies in the oil palm industry and improve their knowledge of oil palm management. Felda Global Ventures (FGV) [70] suggests that extension training within the oil palm industry should prioritize enhancing expertise in sustainable oil palm management, refining production skills, and fostering understanding of Good Agricultural Practices (GAP). In addition, introduce and educate growers about pests in oil palm as well as integrated pest management, train laboratory personnel in determining precise instruments and methods for analysis of fertilizer, water and palm oil, and build a working environment and continuous improvement process [70].

3.3. Centers for the Training of Professional Extension Services Agents

There are several centers in Malaysia, such as Universiti Putra Malaysia (UPM) Center for Extension, Entrepreneurship, and Professional Development (APEEC) and Universiti Utara Malaysia (UUM), Universiti Malaysia Sarawak (UMS), Multimedia University (MU), Universiti Kebangsaan Malaysia, Universiti Teknologi MARA, and the Centre for Environment, Technology and Development, Malaysia–CETDEM [71]. These institutions provide short training courses and offer special training programs for extension agents on request. Additionally, some private agricultural companies and autonomous agricultural authorities provide in-service training, such as the Malaysian Agricultural Research and Development Institute (MARDI) [72]. The training programs cover a variety of topics, including agronomic practices, farm management, marketing, post-harvest handling processing, and agribusiness; extension services also include novel plantation techniques and technologies to push a higher number of oil palm growers into using technologies that are new to propel productivity upwards [73, 74]. Commodity organisations are tasked with functions like enforcing the law, marketing, and quality control. Some of the institutions also engage in extension activities, which are closely related to farming activities such as the Federal Agricultural Marketing Authority (FAMA), Agricultural Development Authority (MADA), Integrated Agricultural Development Authorities (IADAs) [75], technical extension unit of the Malaysian Palm Oil Board (MPOB) provide services in soil management services, soil surveying, maps, pest control, and also provide extension services related to soils and crop protection [73].

3.4. The Role of Extension Services in Oil Palm Production

The key roles of extension agents in Malaysian oil palm production include fostering transformation in attitudes, behavior, and social organization within an oil palm plantation or cluster of oil palm growers[38, 76]. Extension agents also motivate oil palm growers to identify and engage with their challenges, offering solutions, demonstrating implementation methods, and encouraging adherence to guidance provided by extension agents[38, 76–78]. They establish connections between government entities, non-governmental organizations, processing companies, markets, and oil palm growers[38]. Extension agents recognize the need for changes to optimize Fresh Fruit Bunch (FFB) yield production, thereby initiating the process of change[78]. Additionally, they furnish robust and practical advice to oil palm growers, particularly smallholders, to address their challenges and enhance oil palm production. Finally, extension agents influence decision-making processes and provide pertinent information and innovative solutions to benefit farmers[79]. In addition to participating in extension programs, extension agents organize training for growers at cluster and plantation levels, respond to grower inquiries, identify relevant committee members, and develop extension programs based on felt and unfelt needs. Furthermore, extension agents can serve as resource linkers, apply extension philosophy, understand extension process/procedure, use statistical tools to evaluate programs, apply adult learning theory, and develop evaluation criteria for their programs[80–84].

3.5. Extension Agents as Facilitators in Oil Palm Insurance Scheme

Apparently, insurance has been used by many countries to help manage agricultural risks[85–87]. Extension agents provide basic and technical information for oil palm insurance especially to smallholder farmers[84, 88, 89]. Abdul Ghani[90] argued that oil palm insurance is seen as an effective method of tackling production risks and adaptation to climate change. Aditya et al.[91] and Zhang et al.[92] disclosed that encouraging farmers to purchase oil palm insurance, as it mitigates the impact of dramatic drops in palm oil prices, climate change, floods, droughts, and other natural disasters on oil palm production. Coble and Knight[93] and Vyas et al.[94] disclosed that it is essentail for extension agents to identify with farmers that oil palm insurance increases stability in income, minimal debts, technological advancement, yield protection, and increasing awareness of production risks. In addition, aside from advising farmers on insurance, extension agents are also expected to link oil palm farmers with public and private insurance companies[95]. There have, however, been concerns raised about relevance of oil palm insurance[16]. According to some analysts, oil palm insurance is too expensive and can only be sustained through government subsidies[96]. Others say oil palm and other crops insurance is financially viable[90]. Malaysia has had crop insurance but on a small scale and as an extension of fire insurance. There is no insurance tailored for oil palm per se[90]. New insurance options can be facilitated and mediated by extension service agents, stakeholders, and relevant government agencies to promote adaptation to changing climate and variability[97, 98]. Davis et al.[18] argue that extension services play a crucial role in facilitating adaptation and risk mitigation by connecting various stakeholders, such as smallholders, researchers, insurance providers, input dealers, and other market participants.

3.6. Building and Strengthen Resilience in Oil Palm Production

In addition to market fluctuations, poor governance, and disease, smallholder oil palm growers are among the most vulnerable populations to climatic shocks. Davis et al.[81] and Basaruddin et al.[58] claim that extension services strengthen oil palm growers' resilience by providing resource inputs and knowledge, tangible and intangible. Additionally, extension services may contribute to improving the resilience of the oil palm sector in general by promoting production and rural development[16, 57, 81]. Davis et al.[81] observed that extension services are now tasked with a broader array of responsibilities beyond their traditional role of promoting production innovation and technology adoption. These expanded duties encompass addressing diverse is-

sues such as human nutrition, risk management, disaster response, adaptation to climate change, and facilitating recovery efforts following emergencies. According to Davis et al.[81], these challenges not only affect extension workers but also impact growers. To address these issues, extension services could boost the capacity and resilience of oil palm growers in various ways. By establishing connections at different levels (local, subnational, and national), they can coordinate multiple oil palm growers' organizations and offer more tailored services[99]. To achieving harmonization, relevance, effectiveness, and timeliness in intervention strategies, Davis et al.[81] argued that extension service agents should identify pertinent actors and collaborate to align short-term emergency responses with long-term resilience-building strategies. Other roles of extension services include assisting growers in making informed decisions regarding consumer preferences, regulatory structures, quality standards, and the effects of climate change on the environment[82, 100, 101]. In addition, a database of growers who require outside support can be created, and extension services can pinpoint growers who are most susceptible to shocks and tailor their assistance accordingly[81, 102].

3.7. Sustainability and Certification

In order to increase productivity in sustainable ways, extension agents provide basic information to oil palm growers[103]. As demonstrated by Hersman[104] and Allahyari[105], establishing a comprehensive network of sustainable plantation education information is indispensable for achieving sustainability in the realm of agriculture. This network should encompass a wide range of educational resources, including but not limited to, practical guides, workshops, seminars, online platforms, and outreach programs tailored to the specific needs and challenges of the agricultural sector. Moreover, it should actively involve stakeholders such as farmers, researchers, policymakers, and industry experts to ensure the dissemination of accurate, up-to-date information and the fostering of collaborative efforts towards sustainable agricultural practices. Kapia-Mendano[65] found that extension services play a crucial role in bringing to light the state of the environment, as well as the dangers and unsustainable practices associated with current oil palm production. Furthermore, extension services can demonstrate sustainable plantation practices in response to climate change[65]. Extension services are crucial in the oil palm certification scheme, as they engage with oil palm growers to raise awareness about the significance of certification and its impact on the environment and society. Through global standards and multistakeholder governance, these promote the development and use of sustainable palm oil products[106]. The Roundtable for Sustainable Palm Oil (2020) reports that "a comprehensive study showed that RSPO Certified Sustainable Palm Oil has 35% lower climate change impacts than non-certified palm oil". Certification necessitates management, administration, quality control, marketing, and service delivery skills, which are beyond the capabilities of smallholders to develop if they are not provided with support, skill and extension services[107].

3.8. Agroforestry and Intercropping

According to Laroche et al.[108], an expanding variety of agricultural settings have started embracing agroforestry and intercropping systems as a possible alternative to conventional monoculture systems to tackle ecological and socioeconomic challenges. Research conducted by Ecological Trends Alliance and Tropenbos International[109] confirmed that intercropping offers farmers the opportunity to broaden their production scope beyond a single crop, enabling diversification into food, fodder, fuel, and timber. This diversification serves as a safeguard against crop failure or the adverse effects of fluctuating prices for primary produce. Additionally, intercropping with legume crops contributes nitrogen to the soil, while mixed species cultivation enhances biodiversity, potentially reducing pest and disease pressures, and enhancing the environmental benefits provided by plantations. According to Buyinza and Wambede[110], plantation owners should receive training and education from extension agents on selecting the suitable plants for agroforestry and intercropping to mitigate the risks of climate change, pests, and diseases. The intensification of oil palm plantations results in adverse environmental impacts, which can be mitigated by oil palm agroforestry and intercropping[111]. Scherr and Partners[112] argued

that agroforestry and intercropping services by extension agents are designed to encourage oil palm growers to engage in agroforestry and intercropping for sustainability. Agroforestry contributes to climate change adaptation and mitigation by sequestering carbon and reducing greenhouse gas emissions [113, 114]. In addition to improving resource use efficiency, improving soil water holding capacity, and increasing pollination services and natural pest control, intercropping can strengthen and stabilize agroecosystems under climate change [115].

3.9. Strengthening Farmers' Education in Oil Palm Production

As per Nabara and Norsida [59], extension services should enhance adult non-formal education by disseminating relevant information through various channels such as printed materials, electronic media (including flyers, radio, television, and the internet), field demonstrations, and growers' field schools. The main goal should be to strengthen community resilience and capacity to address climatic hazards effectively. This includes educating stakeholders on proactive engagement with various parties and utilizing soft skills like communication, team-building, and fostering knowledge-sharing networks to implement efficient climate change adaptation strategies. It is common for rural oil palm growers to lack the most current information on the most efficient and economically responsible way to grow oil palm. Rosegrant and Cline [116] argued that providing growers with adequate physical resources needed for implementation as well as improving their knowledge of new techniques and technologies can dramatically increase their productivity and sustainability in oil palm production. Through extension services, oil palm growers should be introduced, convinced, and encouraged to use improved varieties for optimum yield and adaptation to climate change [4, 59]. In addition, extension agents disseminate new ideas, developed by agricultural research stations and scientists to growers [42, 117], and also extension agents are responsible for introducing growers to new plantation technologies and innovations such as climate-smart oil palm production [38]. The role of extension agents in transferring technology and technical skills to oil palm growers in order to increase productivity is critical to the success of extension services [38]. Transferring knowledge, skills, and attitudes from extension agents to oil palm growers requires creating environments that primarily focus on addressing the growers' problems [42, 95]. The latest plantation technology unveiled by MPOB encompasses advancements in oil palm disease management, the creation of biomass products for treating palm oil mill effluent (POME), and the development of machinery for transporting fresh fruit bunches (FFB) within plantations [118].

3.10. Digital Climate-Informed Extension Services

Changes in climate can be adapted to through digital climate-informed extension services can foster adaptation strategies to climate change [99, 119]. Oil palm growers and other supply network actors can also benefit from extension digitization since it facilitates planning for climatic changes that affect oil palm production on a short-term and long-term basis [99]. A variety of services are offered, such as mobile applications, radio stations, online platforms, and digital bulletins derived from climate models, along with extension services that utilize climate information platforms for making informed decisions [40, 99]. According to the Consultative Group on International Agricultural Research (CGIAR), digital extension services have revolutionized oil palm and other crops research and growers' support to reduce poverty, boost productivity, and adapt to climate change. Through digital extension services, growers' behavior, scientific models, and a real-time monitoring system are being developed to help reduce poverty, boost productivity, and adapt to climate change [120]. The oil palm industry has a great opportunity to improve climate change adaptation through digital extension and services.

4. Poverty Alleviation

Oil palm and other agricultural extension programs are widely studied for their role in reducing poverty in rural areas [121]. According to Edwards [59, 84], oil palm extension services can reduce poverty and income inequality in districts with the highest levels of poverty. According to Olagunju et al. [122], extension services reduce

poverty status among rural palm oil processors. In general, the larger the frequency with which a processor is in contact with extension workers, the more productive he or she will be [40, 122]. Also, Alwarritzi et al. [123] and Nabara and Norsida [59] confirmed that access to extension agents' services increase efficiency in oil palm production, reduce poverty, increase farmers knowledge and awareness on climate change adaptation. For example, Javeid and Nawab [101] argued that each visit to farmers by extension agents reduces headcount poverty and increase production level. Oil palm production alleviate poverty in Malaysia from 50% in 1960s to about 5% today [55]. There are more than 570,000 people employed directly by the palm oil industry in Malaysia, and another 290,000 people are employed downstream [124, 125].

4.1. The Role of Information and Communication Technology (ICT) in Oil Palm Plantation Extension Services

Information and communication technology (ICT), big data analytics and data science help supply current information on the market price of oil palm products, input, and consumer preferences, which can greatly enhance the growers' negotiation strategy [126]. The big data approach, if adopted by extension services, would help overcome the challenges faced in integrating smallholders into environmentally friendly oil palm production [127]. The availability of comprehensive and clear data will greatly aid in obtaining better, more accurate data on the extent of oil palm cultivation and its impact, positive or negative, on the environment or on humanity [128]. Oil palm growers are able to easily gain updated and pertinent information through ICT, for the purchase of quality seeds, credit and insurance, irrigation water supply, plantation management, and market prices. ICT plays a variety of crucial roles in plantation extension service delivery, such as: aiding in reaching a larger number of smallholder oil palm growers, offering solutions for resource and capacity challenges in the oil palm sector; enhancing knowledge transfer and connecting smallholder farmers in remote areas, plantation management (transplanting, spraying, fertilizer application, pest and disease control, FFB transportation, etc.) [129], and responding to questions about plantation problems with the benefits of receiving feedback via mobile phone and other social media platforms [76, 126, 130, 131].

4.2. The Role of Department of Agriculture and Integration Research and Extension Division in Oil Palm Extension Services

The Department of Agriculture and Integration Research and Extension Division play key roles in oil palm extension services. These services encompass various aspects: (i) extension services in oil palm production, which focus on tasks like field preparation, selection of planting materials, weed and pest controls, and fertilizer application [59, 79]; (ii) pesticide extension services, aimed at training growers in the use of recommended pesticides and implementing integrated pest management techniques [132]; (iii) Diagnostic extension services, where extension workers analyze oil palm roots, fronds, trunks, and foliage (crown) to diagnose pest and disease infections, nutrient deficiencies, and other issues; and (iv) harvesting extension, providing services throughout pre-harvest, harvest, and post-harvest activities [79]. In addition, growers are advised on agroecological practices [59, 79], (v) extension services in oil palm and allied products processing; concern with the increasing industry awareness of the importance of adding value to oil palm products, (vi) marketing extension services; focused on encouraging growers to be involved in contract farming [133]. In order to guarantee market outlets, growers, no matter how small or large, are encouraged to enter into formal contracts with buyers, wholesalers, or retailers [59, 79]. Additionally, DOA and IRED emphasize technology transfer from research agencies to extension agencies and finally to clients, such as growers, entrepreneurs, and investors [79]. The plantation communities are expected to benefit from technology transfer activities in terms of increased income and improved quality of life.

4.3. The Role of Drone in Data Collection and Oil Palm Extension Services

As a cost-effective alternative to plantation and farm embedded systems, information gathering, and

data assessment using unmanned aerial vehicles (UAVs) have emerged in recent years [134]. The UAVs can be remotely piloted by a human operator or programmed to fly autonomously for a specified purpose [135]. It has the advantages of extensiveness, non-invasiveness, timeliness, and flexibility, and for areas of 5 hectares [135]. Drones used in oil palm plantation provide numerous benefits to growers, including the ability to save money on management by increasing yield and productivity [136]. The drone can be used to count palms, spray nutrients with a nutrient applicator, map the area, soil properties, yield, oil palm cover, oil palm pathogen detection, irrigation performance, oil palm water status, measure plant health using the Normalize Difference Vegetation Index (NDVI), and high spatial resolution images captured by UAV provide a reliable prospect for detecting palm trees with a distinctive crown formation [134, 137]. The UAV technology has been widely used in extension services. For instance, Japan has over 10,000 drones for agricultural operations, while India utilizes UAVs to monitor the health of coffee. Banana, sugarcane and rice production were monitored using UAVs in Panama, Europe and Asia [138, 139]. The use of a drone is an efficient way of taking inventory of oil palm tree stands at the owner's convenience without the usual several days of hard labour. This method significantly reduces counting errors. Increasingly, drones are used in oil palm plantations to monitor, collect data, and monitor pests, as well as spray herbicides and pesticides [137].

Using UAVs can be highly beneficial for extension agents in developing programs that involve youth and adults, leading to increased participation levels, production, and influencing climate change adaptation [135]. In addition to the technology being relatively new, most oil palm growers are unlikely to be familiar with operating UAVs on their plantations. Extension professionals can develop and implement programs and curricula for the use of UAVs [135]. In spite of this, there is a pressing need for pragmatic guidance on UAV interest, relevant programming requirements, and/or methods for integrating UAV technology with extension activities.

4.4. Private Extension Services Provided in the Oil Palm Sector

Wanigasundera and Atapattu [140] categorized the entities providing private extension services into three categories: (i) organizations dealing with plantation inputs such as chemicals and fertilizer, (ii) development agencies comprising government and non-governmental organizations, and (iii) grower-based associations, cooperatives, and societies. **Table 2** highlights Private Extension Services in the Malaysian Oil Palm Sector.

Table 2. Private Extension Services in the Malaysian Oil Palm Sector.

Category	Private Firms/Entities
Plantation Inputs	Farm Irrigation Systems Development, Agro-tourism, Seed Production Technology, Agro-based Industry Development
Development Agencies	Tropicrop, Landmark Plantation Group, AgroTop Plantation Services, Applied Agricultural Resources (AAR) [141–143]
Grower-Based Associations/Cooperatives/Societies	Farmers Organization Authority, Sarawak Oil Palm Plantation Owners Association (SOPPOA), Malaysian Palm Oil Association, Palm Oil Refiners Association of Malaysia, Malaysian Palm Oil Council, Malaysian Palm Oil Certification Council [73, 144–146]

4.5. Identification of Priority Needs in Extension Services for Oil Palm Growers

Extension services play a critical role in increasing agricultural productivity, improving food security, advancing livelihoods in rural areas, and elevating agriculture as an economic growth engine for the poor [147]. Extension agents can assist in seed and inputs provision, as well as determining which inputs are appropriate in the face of climate change and which can be sourced locally [148]. Farmers can also benefit from the assistance of extensionists in learning how to use new varieties.

In terms of climate change, a key future problem for extension services will be the shift from supplying advice 'packages' in technology and management to giving growers the needed skills and information for making

decisions that are based on knowledge. Therefore, farmers need frequent access to data on weather patterns in addition to being trained in the interpretation of that data and adapting their plantation management practices as required [149]. On the other hand, growers might need to consider new options in technology and management if climate change or other shocks or stresses that cause their current production systems to become non-viable [150]. There is an urgent need for financing, as in the next 25 years (2017–2041) oil palm plantations will need replanting annually; approximately 175,000 ha in planted areas will need USD 700 million each year in long-term replanting financing [42, 151]. Substantial funding in terms of soft loans to oil palm smallholders from commercial banks to boost oil palm cultivation and improve standards of living is needed [142]. As a result, banks should invest in low-cost infrastructure (agent banking via cooperatives for instance) and the capability to evaluate and manage credit risks for individual farmers. There is also need for assistance and incentives for smallholders so they can invest in sustainable plantation management practices [152]. Investors regard the Round Table on Sustainable Palm Oil (RSPO) certification as a highly credible program to promote sustainability in oil palm cultivation. Growers require support and extension services for sustainability in oil palm cultivation through certification.

Another area where these services and resilience intersect is in tools for sharing information, namely information and communication technology (ICT). Farmers' risks and uncertainties are often exacerbated by information scarcity regarding weather, inputs, farm management practices, or market prices. A dearth of information can negatively affect production and subsequently, income. Consequently, a grower who has access to up-to-date and high-quality information and is able to act on it may be able to reduce the impact of these risks [153]. Growers' behaviour patterns can be influenced by mobile information services, which can promote the diffusion of information and the utilisation of better techniques, resulting in higher yields. Weather and price information can be used by farmers to minimise production and market risks [154]. Information sharing and tools like ICT can mitigate possible risks, while other instruments such as weather insurance can act as compensation for risks that have come to pass [81, 155].

4.6. Challenges and Prospects in Oil Palm Extension Services

It is extremely difficult to provide effective extension services in the oil palm sector due to the following challenges; lack of capacity building among extension agents, inadequate training experience, lack of regular in-service workshops, and insufficient staff to reach out to growers [156]. Other challenges are inadequate access to ICTs that are necessary to support new approaches in oil palm extension services, lack of funding, lack of growers' participation, unavailability of extension tools, and lack of support from the extension administration. Nagiah and Azmi [107] reported that independent oil palm smallholder farmers in Malaysia encounter challenges such as limited institutional, technical, and financial support, as well as a lack of knowledge regarding best practices and new technologies. They also face difficulties due to limited external assistance in the form of training, credit services, seedlings, or fertilizer. For instance, Kannan et al. [157] highlight that the ratio of extension agents to smallholders is 1:1500, posing challenges in providing extension services to all smallholders, particularly for MSPO certification, which became mandatory by December 31, 2019. Despite these challenges, there is light at the end of the tunnel for the oil palm industry. Malaysian oil palm growers and stakeholders can learn from other countries such as the United States, Indonesia, Russia, and India, etc., by increasing funding for adaptation to climate change in oil palm plantations, digitizing oil palm production, embracing solar irrigation during the dry season, and encouraging smallholder growers to diversify. It is possible to automate plantation operations and irrigation with robotic systems. Oil palm plantations can become more profitable, efficient, safer, and environmentally friendly by making use of moisture and temperature sensors, aerial imagery, and global positioning system (GPS) technology. There are many promising aspects of oil palm production, including precision agriculture, industrial automation, automated irrigation systems, remote monitoring of planta-

tions, genetic engineering, genetically modified palms, combining datasets, smart technology such as precision sprayers, digital plantation production, data integration and collection, weather forecasting, and field management. Through extension service agents, these technologies and modern production methods can be disseminated to oil palm growers.

4.7. Policy Recommendations and Research Gap

For effective extension delivery in the oil palm sector, this study suggests some useful policy and research recommendations. Establishment of central agency to plan, coordinate, and implement extension services in the oil palm sector, and decentralize the administration to states and provinces. Employment of young vibrant extension agents, and provision for regular training and workshops for effective service delivery. Malaysia has a number of higher education institutions, but they are not yet quantified as participating in extension services. More funds should be generated and allocated to conduct research on oil palm plantation and climate change from agricultural extension perspective. Increase the capacity of individuals, organizations, and systems to adapt to climate change and risk by enhancing resilience-building initiatives, implementing sustainable practices, fostering community engagement, and promoting knowledge-sharing networks. Sustainability and resilience should be integral considerations in policy coherence. To enhance growers' resilience, it is essential to formulate policies that clearly define the role of extension services in the plantation sector. Despite the existence of policies and guidelines, documenting the success rate of policy implementation is necessary. Equipping extension services with systems and procedures for managing human and financial resources, along with institutional structures that facilitate collaboration and learning, is imperative. Both public and private extension agencies, as well as growers, should adopt ICTs to mitigate risks and enable rapid response. Regarding climate change and oil palm extension services, there are significant empirical research gaps. There is a pressing need for in-depth studies to understand the prerequisite competencies for an extension agent to effectively support oil palm growers. Addressing climate change from the perspective of extension agents involves implementing strategies to mitigate its impact and promote resilience within the agricultural sector. Concurrently, efforts should be made to expand the capacity of extension services to effectively address key resilience challenges in the oil palm industry. This entails applying and testing various extension service models to optimize service delivery, while also considering growers' perceptions of these services. Understanding the rate of acceptance of new innovations and technology among growers is crucial, along with identifying the determinants influencing their acceptance. By addressing these factors comprehensively, extension agents can play a pivotal role in facilitating adaptation to climate change and fostering sustainable practices within the oil palm sector.

5. Conclusion

Understanding the potential role of extension services in the oil palm sector is critical. It is essential that Malaysia, as the second largest exporter of palm oil, understands the interplay between oil palm, climate change, and extension services for sustainability. In this study, the role of extension services in Malaysian oil palm production was reviewed. Climate change significantly impact oil palm production and necessitate mitigation measures. The impact of rising temperature and heavy rainfall negatively affects the production of oil palm. Oil palm growers can adopt and achieve self-sufficiency with the assistance and guidance of extension services. In order to increase oil palm productivity and adapt to climate change, extension services are important. Extension agents provide necessary information, new innovation and technology to oil palm growers and strengthen their capacity to adapt to the impact of climate change. It should also be noted that agricultural extension improves the efficiency with which adaptation decisions are made. It is the most important source of information available to oil palm growers for analysing adaptation decisions. Part of the extension agent's responsibility is to provide knowledge, information, and technology to growers and other market participants. Besides providing growers with technical and organiza-

tional assistance, extension agents should ensure that they engage in interactions with researchers, educators, agribusinesses, and other relevant institutions.

Authors Contribution

A.A., S.K., M.Y.I., M.K.U.: Conceptualization, Writing - Review and Editing. S.K., M.Y.I.: Validation, Formal Analysis. A.A., M.Y.I., M.K.U.: Resources. A.A., S.K., M.Y.I., M.K.U.: Data Curation, Writing—Original Draft Preparation, Visualization, Supervision, Project Administration. S.K.: Funding Acquisition. All authors have read and agreed to the published version of the manuscript.

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The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no competing interests.

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