EFFICACY AND COST EFFICIENCY OF WEED MANAGEMENT USING GENERIC HERBICIDE, ADJUVANT AND DRONE APPLICATION IN OIL PALM PLANTATIONS

By

KAMALUL ADHAM BIN CHE RUZLAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

October 2023

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DEDICATION

This thesis is dedicated to
my parents Che Ruzlan Mahmood and Radziah Khadijah Zakaria
and my beloved wife Ummi Rose Azra Mohd Tajuddin
and daughter Asma' Rumasiya Kamalul Adham
With love, respect and a bunch of memories
indeed, we belong to Allah and indeed to Him we will return

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Associate Professor Muhammad Saiful bin Ahmad Hamdani, PhD
Faculty : Agriculture

A strategy that balances effective weed control and costs in oil palm plantations is crucial amidst rising herbicide expenses and soil erosion concerns. Herbicides offer cost-effectiveness and efficacy method over manual weeding. However, rising herbicide costs, exemplified by the 39% increase in Felda Global Ventures (FGV) in 2021, demand immediate attention. Therefore, this study aims to optimize herbicide efficacy and cost efficiency by addressing weed management challenges, comparing premium and generic herbicides, evaluating the additive effect of WEED Solut-ioN®, and assessing drone-assisted blanket spraying and purification of legume cover crops during replanting. The research utilized questionnaires and field experiments. The survey covered FGV plantations across Malaysia, with experiment trials conducted at Tun Razak Agriculture Centre, Jengka, Pahang and Felda Global Venture Plantation Malaysia (FGVPM) Mengkarak 2, Bera, Pahang. In study 1, two surveys were conducted in oil palm plantations across Malaysia: one on weed management practices and issues, and another on the performance of generic herbicides. Chemical (herbicide) approach was the predominant weed control approach employed, followed by biological control, mechanical control, integrated weed management, and cultural practices. Common issues faced by planters included labor, herbicide resistance, high cost, knowledge, practical issues, low productivity, and herbicide efficacy. The survey on generic herbicide performance revealed that most planters favored generic products due to cost. However, they noted issues like inconsistent weed control and less effectiveness.

Study 2 found that generic herbicides performed similarly to premium herbicides. Across all assessments in both immature and mature oil palm settings, generic herbicides achieved 93% to 97% of weed control efficiencies compared to the slightly superior control by premium herbicides (98% to 100%). Cost projections indicated substantial cost savings associated with the use of generic herbicides, with a 47% cost

reduction in immature stages and around 12% in palm circles. Savings for controlling broadleaf and woody weeds approached 14% in both scenarios. Given that all generic herbicides assessed in this study achieved over 90% weed control efficiency, their adoption presents a cost-effective alternative to premium herbicides. Study 3 revealed the effectiveness of WS in reducing the amount of herbicide required to control weeds, resulting in a 50% of reduction in herbicide dosage for circle weeding in immature oil palms and 70% for inter-row weeding and selective weed control of *C. hirta* in mature oil palms. Phytotoxicity evaluations on eight-month-old oil palm trees indicated WS as a non-phytotoxic reductant, posing no harm to oil palm growth or yield, with minimal impact on *Elaedobius kameranicus* (weevils) even at a higher concentration (at 2 L/ha). Economic analyses demonstrated the substantial cost-saving potential of WS, resulting in up to 25% of reduction for immature palms and up to 14% for mature palms. Overall, WS can save FGV up to RM10,776,617 per year on weeding costs. WEED Solut-ioN® emerges as a highly effective and sustainable solution for weed control in oil palm plantations.

Study 4 showed that 0.25 MPa pressure was more effective than 0.15 MPa as it provided broader coverage and more droplets. In replanting areas, both UAV and mistblower applications resulted in 100% weed eradication, demonstrating equal effectiveness. In pre-planting zones, the initial advantage of conventional knapsack sprayers (CKS) diminished over time, highlighting the UAV spray's enhanced efficacy. UAV spraying becomes cost-effective for areas over 3,000 hectares, with potential savings ranging from 4% to 28%. Furthermore, UAV spraying reduced working hours by 37%, water usage by 91%, and human expenses by 81% compared to conventional methods, highlighting its efficiency and cost saving benefits for large-scale weed control in oil palm plantations. Overall, this research offers insights into optimizing weed control in oil palm plantations, emphasizing cost efficiency and sustainability through strategic herbicide selection, additive solutions like WEED Solut-ioN®, and innovative techniques such as UAV spraying.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KEBERKESANAN DAN KECEKAPAN KOS PENGURUSAN RUMPAI DENGAN MENGGUNAKAN RACUN RUMPAI GENERIK, ADJUVAN DAN APLIKASI DRON DI PERLADANGAN KELAPA SAWIT

Oleh

KAMALUL ADHAM BIN CHE RUZLAN

Oktober 2023

Pengerusi : Profesor Madya Muhammad Saiful bin Ahmad Hamdani, PhD
Fakulti : Pertanian

Strategi yang mengimbangi kawalan rumpai yang berkesan dan kos di ladang kelapa sawit adalah penting kerana kos perbelanjaan racun rumpai semakin meningkat dan dengan kebimbangan hakisan tanah. Racun rumpai menawarkan kos dan kaedah yang berkesan berbanding dengan merumput secara manual. Bagaimanapun, peningkatan kos racun rumpai setinggi 39% yang ditunjukkan oleh Felda Global Ventures (FGV) memerlukan perhatian segera. Oleh itu, kajian ini bertujuan untuk mengoptimumkan keberkesanan racun rumpai dan kecekapan kos dengan menangani cabaran pengurusan rumpai, perbandingan antara racun rumpai premium dan generik, menilai adjuvan WEED Solut-ioN®, dan penilaian semburan hamparan dan penulenan kekacang penutup bumi dengan menggunakan dron. Penyelidikan ini menggunakan soal selidik dan eksperimen berasaskan kajian lapangan. Soal selidik tersebut meliputi perladangan FGV di seluruh Malaysia dan kajian lapangan dijalankan di Pusat Pertanian Tun Razak, Jengka, Pahang dan Felda Global Venture Plantation Malaysia (FGVPM) Mengkarak 2, Bera, Pahang. Dalam kajian 1, dua soal selidik telah dijalankan di ladang kelapa sawit di FGV seluruh Malaysia: yang pertama mengenai amalan dan isu pengurusan rumpai, dan yang kedua mengenai prestasi racun rumpai generik. Racun rumpai adalah pendekatan kawalan rumpai utama yang digunakan, diikuti oleh kawalan biologi, kawalan mekanikal, kawalan kultura dan pengurusan rumpai bersepadu. Kebiasaan isu yang dihadapi oleh peladang ialah buruh, kerintangan racun rumpai, kos racun yang tinggi, pengetahuan berkaitan pengurususan rumpai, isu praktikal, produktiviti yang rendah dan keberkesanan racun rumpai. Soal selidik mengenai prestasi racun rumpai generik menunjukkan bahawa kebanyakan peladang memilih produk generik kerana kos yang lebih murah. Walaubagaimanapun, peladang melaporkan isu seperti kawalan rumpai yang tidak konsisten, kos yang tinggi dan keberkesanan racun yang rendah.

Kajian 2 mendapati bahawa racun rumpai generik mempunyai prestasi yang setanding dengan racun rumpai premium. Penilaian di dalam kelapa sawit pra matang dan matang menunjukkan bahawa racun rumpai generik hanya mencapai 93% hingga 97% kecekapan kawalan rumpai berbanding racun rumpai premium yang menunjukkan kawalan yang lebih baik (98% hingga 100%). Dari segi unjuran kos, racun rumpai generik menunjukkan penjimatan kos yang tinggi iaitu 47% di dalam peringkat pra matang dan sekitar 12% di peringkat matang. Penjimatan kos untuk mengawal rumpai berdaun lebar dan berkayu menghampiri 14% di dalam kedua-dua kategori. Memandangkan semua racun rumpai generik yang dinilai dalam kajian ini mencapai lebih daripada 90% kecekapan kawalan rumpai, penggunaannya memberikan alternatif kepada racun rumpai premium dari segi kos efektif. Kajian 3 menunjukkan keberkesanan WEED Solut-ioN® (WS) di dalam mengurangkan 50% kadar racun rumpai yang diperlukan untuk mengawal rumpai di bulatan kelapa sawit pra matang dan pengurangan 70% untuk merumput antara barisan kelapa sawit dan kawalan anak kayu (*Clidemia hirta*) di kelapa sawit matang. Penilaian fitotoksisiti pada anak pokok kelapa sawit berusia lapan bulan menunjukkan WS tidak memudaratkan pertumbuhan kelapa sawit (bukan fitotoksik), dan memberi kesan minimum terhadap *Elaedobius kameranicus* (kumbang pendebungaan) walaupun pada kepekatan yang lebih tinggi (2 L/ha WS). Analisis kos menunjukkan potensi penjimatan kos yang tinggi dengan menggunakan WS, 25% pengurangan untuk sawit yang belum matang dan 14% untuk sawit matang. Secara keseluruhanya, WS boleh menjimatkan kos merumput di FGV sehingga RM10,776,617 setahun. WEED Solut-ioN® muncul sebagai penyelesaian yang berkesan dan mampan untuk kawalan rumpai di ladang kelapa sawit.

Kajian 4 menunjukkan bahawa tekanan 0.25 MPa adalah lebih berkesan berbanding 0.15 MPa kerana ia memberikan liputan yang lebih luas dan lebih banyak titisan. Di peringkat tanam semula, kedua-dua aplikasi UAV dan *mistblower* membasmi 100% rumpai dan menunjukkan keberkesanan yang sama. Di peringkat pra-penanaman, kelebihan awal penyembur kocok konvensional (CKS) berkurangan dari semasa ke semasa, manakala keberkesanan semburan UAV yang semakin meningkat. Penyemburan UAV adalah kos efektif untuk kawasan seluas 3,000 hektar dengan potensi penjimatan antara 4% hingga 28%. Selain itu, semburan UAV mengurangkan waktu kerja sebanyak 37%, mengurangkan penggunaan air sebanyak 91%, dan mengurangkan penggunaan tenaga buruh sebanyak 81% berbanding kaedah konvensional, menonjolkan kecekapan dan faedah penjimatan kos untuk kawalan rumpai berskala besar di ladang kelapa sawit. Secara keseluruhannya, penyelidikan ini menawarkan penyelesaian untuk mengoptimumkan kawalan rumpai di ladang kelapa sawit, menekankan kecekapan kos dan kelestarian melalui pemilihan racun rumpai, adjuvan seperti WEED Solut-ioN®, dan teknik inovatif seperti penyemburan UAV.

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This thesis was submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Muhammad Saiful bin Ahmad Hamdani, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Abdul Shukor bin Juraimi, PhD
Professor Dato'
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Mashitah binti Jusoh, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 March 2024

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ANOVA	Analysis of Variance
A.I.	Active Ingredient
BMP	Best Management Practices
CKS	Conventional knapsack sprayer
CDA	Controller droplet action
COVID-19	Coronavirus disease of 2019
CIRP	*Christmas Island Rock Phosphate*
CPO	Crude palm oil
CDA	Control droplet applicator
CapEx	Capital expenditures
DAT	Day after treatment
DAS	Day after spraying
D×P	Dura × Pisifera
Delta T	Temperature difference
EPA	Environmental Protection Agency
EFB	Empty fruit bunch
EPSP	5-enolpyruvlyshikimate-3-phosphate
E. kameranicus	*Elaedobius kameranicus*
ERDAS	Earth Resources Data Analysis System
FGV	Felda Global Ventures
FGVAS	Felda Global Ventures Agri Services
FGVPM	Felda Global Ventures Plantation Malaysia
FGV R&D	Felda Global Ventures Research & Development

FFB	Fresh Fruit Bunches
GDP	Gross Domestic Product
GA	Glufosinate ammonium
GAP	Good Agricultural Practices
Glyphosate IPA	Glyphosate isopropylamine
GWC	General weed control
GPS	Global Positioning System
HRAC	Herbicide Resistance Action Committee
HV	High volume
IWM	Integrated weed management
IBM	International Business Machines Corporation
IDR	Indonesian Rupiah
ISODATA	Iterative Self-Organizing Data Analysis Technique
IUPAC	International Union of Pure and Applied Chemistry
LC_{50}	Lethal concentration 50%
LD_{50}	Lethal dose 50%
LCC	Legume cover crops
LOCI	Laboratory for Optical and Computational Instrumentation
LSA	Liquid spray adjustable
LV	Low volume
MP	Megapixel
MCPA	2-methyl-4-chlorophenoxyacetic acid
MT	Metric tonnes
MSM	Metsulfuron methyl
MV	Medium volume

MSMA	Monosodium methanearsonate
MSPO	Malaysian Sustainable Palm Oil
MOP	Muriate of potash
MPa	Mega Pascal
NAP	National Agricultural Policy
N	Nitrogen
PPE	Personal Protective Equipment
POME	Palm oil mill effluent
PK	Palm kernel
P	Phosphorus
PPPTR	Pusat Penyelidikan Pertanian Tun Razak
PhD	Doctor of Philosophy
RSPO	Roundtable on Sustainable Palm Oil
RCBD	Randomized complete block design
RUP	Restricted use pesticides
RH	Relative humidity
R&D	Research and development
RO	Reverse osmosis
SPSS	Statistical Package for the Social Sciences
SAS	Statistical Analysis System
SOP	Standard operating procedure
SE	Standard error
TBE	Triclopyr butoxyethyl ester
UAV	Unmanned aerial vehicle
ULV	Ultra-low volume

US	United States
UPM	Universiti Putra Malaysia
VLV	Very low volume
VMD	Volume median diameter
VOPs	Volunteer oil palm seedlings
WS	WEED Solut-ioN®
WAT	Week after treatment
WSSA	Weed Science Society of America
WHO	World Health Organization
WSP	Water sensitive paper
%	Percentage
g	Gram
g/ha	Gram per hectare
Kg/ha	Kilogram per hectare
m^2	Square meter
ha	Hectare
m	Meter
ms^{-1}	Metre per second
L	Litre
L/ha	Litre per hectare
ppm	Parts per million

CHAPTER 1

INTRODUCTION

1.1 Background

Popularly identified as Malaysia's "Golden Crop", oil palm (*Elaeis guineensis* Jacq.) is a key driver of the nation's economy as well as an established major export commodity and source of income. The expansive landscapes once dedicated to cocoa and rubber plantations have gradually given way to the more lucrative oil palm, supported by the use of agrochemicals to facilitate the extensive transition. The shift gain significant traction in Malaysia during the late 20th century and continued into the 21st century. This change was primarily due to the increased profitability of oil palm compared to other crops. Oil palm is known for its higher yield per hectare and economic advantages, which incentivized farmers and agricultural companies to replace less profitable crops with oil palm plantations. Governmental policies, market demands, and economic incentives provide further accelerated the transition from traditional crops like cocoa and rubber to oil palm notably from the 1980s onwards. The promotion of agrochemical use, including fertilizers and pesticides, has been a part of modern agricultural practices aimed at boosting oil palm productivity. Agrochemicals are utilised to improve soil fertility, control pests and diseases, and enhance crop yields, however, their usage has raised concerns regarding environmental impact and sustainability.

Palm oil is one of Malaysia's core industries and the country's largest agricultural export worldwide. In 2022, it is expected to contribute 2.4 percent to Malaysia's GDP (Department of Statistics Malaysia, 2022). As the world's second-largest producer and exporter, after Indonesia, Malaysia is projected to export 15 million metric tonnes of palm oil and palm-based products in 2022, valued at approximately 137 billion Malaysian ringgit (Ministry of Plantation Industries and Commodities, 2022). This translates to a staggering 35 billion ringgit contribution to Malaysia's total GDP. As of 2019, the sector contributed 7.1 percent (RM101.5 billion) to the nation's GDP (Department of Statistics Malaysia Official Portal, 2021). The industry's importance is reflected in its Third National Agricultural Policy (NAP) (1998-2010), which priotises continued development of the palm oil sector, particularly in Sabah and Sarawak, with support through reverse investment from neighbouring countries. Ensuring sustainable production through good plant and land management practices is paramount. This includes optimising oil palm trees throughout their life span to achieve high quality and quantitative yields. Efficient weed control, a fundamental and critical aspect of oil palm plantation management, is key to achieving this.

Weeds pose a significant threat to crop production, particularly for oil palm, rubber, and rice. They act as unwelcome competitors by reducing crop productivity and serving as a breeding ground for pests and diseases. In general, weeds have negative impacts on crop growth and yields as they compete, among others, for space and essential nutrients for their use. Weeds are a nuisance that competes with crops for resources in the soil, such as water, light, and nutrients (Zimdahl, 2007), making weed control a vital component in all crop production systems. In oil palm plantations, chemical management techniques using herbicides is the primary approach due to its cost-effectivness and ease of application (Wibawa, 2007). Herbicides yield a faster outcome, reliable efficacy, and straightforward use, making them a seemingly attractive solution (Rutherford et al., 2009). This explains their pervasive use, accounting for over 80% of Malaysian pesticide usage in 2019/2020 (FAOSTAT, 2021).

Effective weed control through herbicides requires both in-depth technical knowledge of numerous weed species and understanding of functional properties of each herbicide. This knowledge, combined with awareness of operating procedures for each herbicide, is crucial for crafting an accurate and economical system of chemical weed control techniques that are less risky to humans, animals, crops, and the environment. The key is optimum amount of herbicides used for maximum outcome because too much use of herbicides is dangerous for the environment. Therefore, it is highly critical to mitigate its hazardous consequences. One promising avenue is to utilise herbicide adjuvants, which contain compounds that have the ability to enhance herbicide efficacy. Even though there are various adjuvants available in the Malaysian market, it is critical to choose the most suitable type of adjuvant to be used in conjunction with current chemical weed control practices to warrant that efficient weed control is achieved.

The oil palm industry faces a dilemma, with a plethora of low-cost generic herbicidal products flooding the market promising weed control at a fraction of the price of premium products. While their low cost appeals, questions remain concerning product quality, effectiveness, and cost-efficiency. Although previous studies have hinted at potential differences between generic and premium herbicides, a comprehensive assessment addressing both effectiveness and cost-effectiveness remains lacking. Jabit et al. (2022) explored this issue by investigating the effectiveness of both name-brand and generic herbicides in controlling weeds in order to determine which herbicide is the best with the lower costs suitable for use in oil palm plantations. Past research has indeed documented the utilisation of generic herbicides in oil palm plantations due to their affordability. However, limited empirical evidence exists regarding their performance in weed control compared to premium herbicides. Previous studies have mostly focused on singular aspects, such as the herbicide's effectiveness or economic considerations, without comprehensive comparative analyses between generic and premium herbicides. Unlike previous studies that often focused on either efficacy or cost-effectiveness separately, this study uniquely provides a comprehensive comparative analysis encompassing both aspects, offering a more holistic view for informed decision-making in weed management practices within oil palm plantations. The existing research gap primarily stems from the lack of comprehensive comparative studies assessing both the efficacy and cost-effectiveness of generic herbicides versus premium herbicides in oil palm plantations. Current studies often overlook one aspect in favor of the other, creating a significant knowledge gap regarding their holistic performance. This study contributes by addressing the research gap regarding the comparative performance of generic and premium herbicide in oil palm plantations.

The comprehensive assessment of efficacy and cost-effectiveness underscores the need for a more nuanced understanding when choosing between generic and premium herbicide for weed management in oil palm plantations.

The current practice for weed control is very labor-intensive and uses tedious equipment including ground-spray operators. The emergence of the unmanned aerial vehicle (UAV) sprayer is fast becoming a popular trend in agriculture due to its high efficiency, time-saving, and ability to operate remotely with minimal manpower (Ji et al., 2022). Drones, also known as unmanned aerial vehicles (UAVs) or unmanned aerial systems (UAS), have gained significant attention and utility in various agricultural applications, including weed management. These aerial vehicles are equipped with cameras, sensors, and sometimes even specialized spraying mechanisms offering the potential for precision agriculture practices. Weed infestation poses a significant challenge in plantations, affecting crop yields and quality. Traditional methods of weed control often involve manual labour or broad-scale application of herbicides, which can be labour-intensive, time-consuming, and may lead to excessive chemical usage, impacting the environment. The use of drones in weed control in plantations shows promise as an innovative and potentially more sustainable approach. However, further research and field studies are necessary to validate their efficiency, cost-effectiveness, and long-term impacts on crop production and the environment.

Recent studies and advancements have explored the use of drones for weed control in plantations. By employing high-resolution cameras or sensors, drones can capture detailed images of the plantation areas, enabling farmers or agricultural specialists to identify weed populations more accurately and precisely. Moreover, some drone systems are equipped with technologies that allow targeted spraying of herbicides directly onto the identified weed patches. This targeted application minimises herbicide usage, reduces environmental impact, and optimises the effectiveness of weed control measures. Previous studies have indeed demonstrated the potential of drone technology in transforming the oil palm industry operation by elevating the effectiveness of oil palm cultivation and production management (Khuzaimah et al., 2022).

Previous studies also have indicated promising results in using drones for weed management in plantations. These studies have highlighted the potential benefits of drones in terms of precision and efficiency. Drones can identify weed hotspots or specific areas requiring treatment more efficiently than traditional ground-based methods, leading to precise and targeted interventions. Besides, drones can help reduced chemical usage. Targeted spraying by drones reduces overall herbicide usage by directly targeting weed-infested areas, thus minimising environmental impact and potential harm to non-target plants. In terms of cost-effectiveness, despite the relatively high initial investment in drone technology, studies suggest potential long-term cost savings due to optimised herbicide usage and increased operational efficiency. Drones also can cover larger areas in a shorter time compared to manual weed control methods, potentially saving time for farmers, and allowing for quicker responses to weed outbreaks.

In terms of the technical aspects in the use of UAVs, meteorological circumstances, such as intensity and wind direction during spraying, can complicate droplet effectiveness. Among the most crucial elements influencing the deposition and drift of herbicide spray is droplet size. The droplet size has a significant impact on both the distribution and leaf-retention of droplets in the sprayed area as well as their drift potential in the non-target area (Chen, 2020). Therefore, to achieve optimal agricultural aerial spraying, it is imperative to examine how different parameters affect droplet distribution and effectiveness in weed control. Addressing challenges associated with manual spraying methods such as inaccessible heights or areas and uneven pesticide distribution is crucial for enhancing operational efficiency. The outcomes would provide optimal spray volume and coverage by UAV utilisation, which is expected to significantly reduce the time needed per UAV operation while maintaining the worker’s safety during the weeding operation.

1.2 Problem statement

Felda Global Ventures (FGV) owns one of Southeast Asia's largest oil palm research facilities, solidifying its position as the industry's leader of innovation and scientific research. It strives to improve agricultural yields sustainably through breeding, tissue culture, agronomy, and crop protection; utilise wastes and by-products to generate new products with greater development potential in higher-margin industries and provide high-quality agro-based products and services. Weeds are among the main constraints in the majority of FGV oil palm plantations. Approximately 15-25% of estate costs involved weeding costs, and the use of herbicides continues to increase every year. Although generic herbicides are commonly used in oil plantations, their efficacy is inconsistent. While generic herbicides may be more cost-effective compared to branded alternatives, variations in formulation and quality can lead to varying levels of effectiveness in weed control. In comparison to other methods, chemicals (herbicides) are the most effective way to control weeds. Oil palm plantations are vulnerable to weed infestations that can significantly impact crop yields and quality. While generic herbicides are commonly used due to their lower costs, their comparative efficacy against premium herbicide remains uncertain. Furthermore, even though integrated weed management has been implemented to control weeds in oil palm plantations, it is not operationally feasible due to the limitations (labor, cost, facilities, etc.). FGV currently employs physical, cultural, mechanical, and chemical weed management methods.

Managing weeds is critical regardless of any stage of crop planting (replanting, nursery, immature and mature). In plantation management, it must be done at a reasonable cost while ensuring high efficiency due to labor scarcity issues, considering it being a labour-intensive task. With the emergence of drone applications in elevating productivity, it promises a potential solution to the problem of effective weed management at a low cost and with minimal manpower. To date, only a few studies have been conducted on drones for weed control. By using aerial spraying to control weeds, FGV can reduce the cost of manpower and time. However, before any recommendation on the use of UAV-based aerial spraying to control weeds in oil palm is made, particularly during the replanting period, a series of extensive evaluations is needed. This is crucial to establish standard operating procedures (SOP) for FGV and to analyse the cost-benefits of UAV spraying for weed control at the replanting stage. Additionally, evaluation of the suitability and cost efficiency of the selected adjuvant (WEED Solut-ioN®) in this study can mitigate the overdosage and skyrocketing herbicide price issue without affecting its effectiveness.

1.3 Objectives

The current study embarked on the determination of the current approach of chemical weed control and the need for a more efficient chemical-based weed management in the FGV plantation. The specific objectives were as follows:

i. To identify the implementation of weed management approaches in the selected FGV oil palm plantations, further reviewing their efficacy and efficiency.

ii. To compare the efficacy and cost efficiency between the premium and generic herbicides in the FGV Jengka oil palm plantation.

iii. To determine the effectiveness and cost efficiency of WEED Solut-ioN® as an herbicide adjuvant in the FGV Jengka oil palm plantation.

iv. To determine the suitability and efficiency of drone spraying in blanket spraying and purification of legume cover crop at the replanting stage in the FGV Jengka and FGV Mengkarak plantation.

REFERENCES

Abdullah, M. R., Zakaria, N., Ahmad-Hamdani, M. S., & Juraimi, A. S. (2020). Evaluation of herbicide efficacy on weed control and grain yield in rice field under flooded condition. *Plant Archives*, *20*, 8163-8169.

Afandi, A. M., Zuraidah, Y., Nurzuhaili, H. A. Z. A., Zulkifli, H., & Yaqin, M. (2017). Managing soil deterioration and erosion under oil palm. *Oil Palm Bulletin*, *75*(November), 1-10.

Ahmad, F., Zhang, S., Qiu, B., Ma, J., Xin, H., Qiu, W., ... & Khaliq, A. (2022). Comparison of water sensitive paper and glass strip sampling approaches to access spray deposit by UAV sprayers. *Agronomy*, *12*(6), 1302.

Al-Gohary, I. H. (2008). Phytogeographical analysis of the vegetation of eleven wadis in Gebel Elba, Egypt. *International Journal of Agriculture and Biology*, 10, 161-166.

Amigo, J. M. (2019). Hyperspectral and multispectral imaging: Setting the scene. In *Data Handling in Science and Technology* (Vol. 32, pp. 3-16). Elsevier.

Arvidsson, T., Bergström, L., & Kreuger, J. (2011). Spray drift as influenced by meteorological and technical factors. *Pest Management Science*, *67*(5), 586-598.

Ayob, M. A., & Kabul, M. H. (2012, September). Cattle integration in oil palm plantation through systematic management. In *International Seminar on Animal Industry*.

Ayamga, M., Tekinerdogan, B., & Kassahun, A. (2021). Exploring the challenges posed by regulations for the use of drones in agriculture in the African context. *Land*, *10*(2), 164.

Barla, P. (2007). ISO 14001 certification and environmental performance in Quebec's pulp and paper industry. *Journal of Environmental Economics and Management*, *53*(3), 291-306.

Baligar, V. C., & Fageria, N. K. (2007). Agronomy and physiology of tropical cover crops. *Journal of Plant Nutrition*, *30*(8), 1287–1339. Doi:10.1080/01904160701554997.

Bastianin, A. (2020). Robust measures of skewness and kurtosis for macroeconomic and financial time series. *Applied Economics*, *52*(7), 637-670.

Baio, F. H. R., Antuniassi, U. R., Castilho, B. R., Teodoro, P. E., & Silva, E. E. D. (2019). Factors affecting aerial spray drift in the Brazilian Cerrado. *PloS One*, *14*(2), e0212289.

Bagavathiannan, M. V., & Davis, A. S. (2018). An ecological perspective on managing weeds during the great selection for herbicide resistance. *Pest Management Science, 74*(10), 2277-2286.

Berner, B., & Chojnacki, J. (2017). Use of drones in crop protection. IX International Scientific Symposium, Farm Machinery and Processes Management in Sustainable Agriculture, Poland.

Berner, B., Pachuta, A., & Chojnacki, J. (2018). Estimation of liquid deposition on corn plants sprayed from a drone. In Proceedings of 25th International PhD Students Conference November 7-8, 2018, Brno, Czech Republic (pp. 403-407). Mendel University in Brno.

Beckie, H. J. (2006). Herbicide-resistant weeds: management tactics and practices. *Weed Technology, 20*(3), 793-814.

Beckie, H. J., Heap, I. M., Smeda, R. J., & Hall, L. M. (2000). Screening for herbicide resistance in weeds. *Weed Technology*, *14*(2), 428-445.

Beckie, H. J., & Harker, K. N. (2017). Our top 10 herbicide-resistant weed management practices. *Pest Management Science*, *73*(6), 1045-1052.

Blair, A. M., & Martin, T. D. (1988). A review of the activity, fate and mode of action of sulfonylurea herbicides. *Pesticide Science, 22*(3), 195-219.

Blackshaw, R. E., Anderson, R. L., & Lemerle, D. E. I. R. D. R. E. (2007). Cultural weed management. Non-Chemical Weed Management: Principles, Concepts and Technology, Wallingford, UK: CAB International, 35-48.

Brown, H. M. (1990). Mode of action, crop selectivity, and soil relations of the sulfonylurea herbicides. *Pesticide Science*, *29*(3), 263-281.

Brand, J., Yaduraju, N. T., Shivakumar, B. G., & Murray, L. (2007). Weed management. In *Lentil* (pp. 159-172). Springer, Dordrecht.

Castaldi, F., Pelosi, F., Pascucci, S., & Casa, R. (2017). Assessing the potential of images from unmanned aerial vehicles (UAV) to support herbicide patch spraying in maize. *Precision Agriculture*, *18*(1), 76-94.

Casimero, M., Abit, M. J., Ramirez, A. H., Dimaano, N. G., & Mendoza, J. (2023). Herbicide use history and weed management in Southeast Asia. *Advances in Weed Science, 40*.

Cerro, J., Cruz Ulloa, C., Barrientos, A., & de León Rivas, J. (2021). Unmanned aerial vehicles in agriculture: A survey. *Agronomy*, *11*(2), 203.

Cerdeira, A. L., & Duke, S. O. (2006). The current status and environmental impacts of glyphosate-resistant crops: a review. *Journal of Environmental Quality, 35*(5), 1633-1658.

Chavan, M. S. (2019). Automatic arial vehicle based pesticides spraying system for crops. *International Journal of Innovative Technology and Exploring Engineering (IJITEE), 8*(11).

Chauhan, B. S., & Johnson, D. E. (2008). Germination ecology of goosegrass (Eleusine indica): an important grass weed of rainfed rice. Weed Science, 56(5), 699-706.

Chauhan, B. S. (2020). Grand challenges in weed management. *Frontiers in Agronomy*, *1*, 3.

Chhokar, R. S., Sharma, R. K., & Sharma, I. (2012). Weed management strategies in wheat-A review. *Journal of Wheat Research*, *4*(2), 1-21.

Chung, G. F., Lee, C. T., Chiu. S. B., & Chee, K. H. (2013). Pictoral guide to common weeds of plantations and their control. *Agricultural Crop Trust (ACT)*.

Chung, G. F. (2013). Integrated management of weeds in oil palm plantations. *Malaysian Palm Oil Board*.

Chung G. F., & Lee C. T. (2009). Weed and ground cover management in oil palm plantation. In *Lecture Notes 11th Intensive Diploma in Oil Palm Management and Technology, Malaysian Palm Oil Board*. 278-297.

Chuah, T. S., Noor-Zalila, M. R., Cha, T. S., & Ismail, B. S. (2015). Paraquat and glyphosate resistance in woody borreria (*Hedyotis verticillata)*) growing at oil palm plantations in Terengganu, Malaysia. *Malaysian Applied Biology, 34*(2), 43-49.

Che'Ya, N. N. (2016). Site-Specific Weed Management Using Remote Sensing.

Charudattan, R. (2001). Biological control of weeds by means of plant pathogens: significance for integrated weed management in modern agro-ecology. *BioControl, 46*(2), 229-260.

Chen, P., Lan, Y., Huang, X., Qi, H., Wang, G., Wang, J., ... & Xiao, H. (2020). Droplet deposition and control of planthoppers of different nozzles in two-stage rice with a quadrotor unmanned aerial vehicle. *Agronomy*, *10*(2), 303.

Christensen, S., Søgaard, H. T., Kudsk, P., Nørremark, M., Lund, I., Nadimi, E. S., & Jørgensen, R. (2009). Site-specific weed control technologies. *Weed Research*, *49*(3), 233-241.

Cléments, D. R., Weise, S. F., & Swanton, C. J. (1994). Integrated weed management and weed species diversity. *Phytoprotection*, *75*(1), 1-18.

Cobb, A. H. (2022). Herbicides and plant physiology. John Wiley & Sons.

Creswell, W. J., & Creswell, J. D. (2018). Research Design: Qualitative, Quantitative and Mixed Methods Approaches. In Journal of Chemical Information and Modeling (5th ed., Vol. 53, Issue 9). SAGE.

Curran, W. S., McGlamery, M. D., Liebi, R. A., & Lingenfelter, D. D. (1999). Adjuvants for enhancing herbicide performance.

Darrel Siekman & Lowell Sandell (2008). Comparing Generic Versus Name Brand Herbicides, Institute of Agriculture and Natural Resources, University of Nebraska.

Délye, C., Jasieniuk, M. & Le Corre, V. (2013) Deciphering the evolution of herbicide resistance in weeds. *Trends Genet. 29*, 649–658.

Department of Statistics Malaysia Official Portal (2021). https://www.dosm.gov.my/v1/index.php.

Department of Statistics Malaysia Official Portal (2022). https://www.dosm.gov.my/v1/index.php.

Dilipkumar, M., Chuah, T. S., Goh, S. S., & Sahid, I. (2020). Weed management issues, challenges, and opportunities in Malaysia. *Crop Protection, 134*, 104347.

DiTomaso, J. M. (2000). Invasive weeds in rangelands: species, impacts, and management. *Weed science*, *48*(2), 255-265.

Duary, B., Dash, S., & Teja, K. C. (2016). Impact of tillage on seed bank, population dynamics and management of weeds. SATSA *Mukhapatra-Annual Technical*, 20.

Duke, S. O. (2017). Pesticide dose–A parameter with many implications. In *Pesticide dose: Effects on the environment and target and non-target organisms* (pp. 1-13). American Chemical Society.

Duffy, J. P., Cunliffe, A. M., DeBell, L., Sandbrook, C., Wich, S. A., Shutler, J. D., ... & Anderson, K. (2018). Location, location, location: considerations when using lightweight drones in challenging environments. *Remote Sensing in Ecology and Conservation, 4*(1), 7-19.

Ecobichon, D. J. (2001). Pesticide use in developing countries. *Toxicology, 160*(1-3), 27-33.

Elezovic, I., Datta, A., Vrbnicanin, S., Glamoclija, D., Simic, M., Malidza, G., & Knezevic, S. Z. (2012). Yield and yield components of imidazolinone-resistant sunflower (*Helianthus annuus* L.) are influenced by pre-emergence herbicide and time of post-emergence weed removal. *Field Crops Research*, *128*, 137-146.

Evans, J. A., Tranel, P. J., Hager, A. G., Schutte, B., Wu, C., Chatham, L. A., & Davis, A. S. (2016). Managing the evolution of herbicide resistance. *Pest management science*, *72*(1), 74-80.

Extoxnet (1996). http://extoxnet.orst.edu/pips/metsulfu.htm.

Fedtke, C. (2012). Biochemistry and physiology of herbicide action. Springer Science & Business Media.

Ferguson, J. C., Chechetto, R. G., Hewitt, A. J., Chauhan, B. S., Adkins, S. W., Kruger, G. R., and O'Donnell, C. C. (2016). Assessing the deposition and canopy penetration of nozzles with different spray qualities in an oat (*Avena sativa* L.) canopy. *Crop Protection*, *81*, 14-19.

Felsot, A. S., Unsworth, J. B., Linders, J. B., Roberts, G., Rautman, D., Harris, C., & Carazo, E. (2010). Agrochemical spray drift; assessment and mitigation—A review. *Journal of Environmental Science and Health Part B*, 46(1), 1-23.

Fernández, V., & Brown, P. H. (2013). From plant surface to plant metabolism: the uncertain fate of foliar-applied nutrients. *Frontiers in Plant Science*, *4*, 289.

FGV. (2022). https://www.fgvholdings.com/home/2022.

Food and Agriculture Organization of the United Nations (FAOSTAT) Agro-Statistics. Database. (2017). Food and Agriculture Organization of the United Nations, Rome.

Food and Agriculture Organization of the United Nations (FAOSTAT). (2021). https://www.fao.org/faostat/en/#home.

Foong, S. Y., & Ho, B. S. (2011). D crop protection Malaysia: competition from generic herbicides. *Emerald Emerging Markets Case Studies*, *1*(1), 1-7.

Franke, T. M., Ho, T., & Christie, C. A. (2012). The chi-square test: Often used and more often misinterpreted. *American Journal of Evaluation*, *33*(3), 448-458.

Gage, K. L., Krausz, R. F., & Walters, S. A. (2019). Emerging challenges for weed management in herbicide-resistant crops. *Agriculture*, *9*(8), 180.

Gacheru, E. N., O'Neill, M. K., Kamau, G. M., Saha, H. M., & Odhiambo, G. D. (1993). Effect of land preparation and weeding on maize (*Zea mays*) grain yields in the coastal region of Kenya. *International Journal of Pest Management*, *39*(1), 57-60.

Gill LS, Onyibe HI (1988) Phytosociological studies of the weed flora of oil palm *(Elaeis guineensis* Jacq.) in Nigeria. *Journal of Plant Crops*, *16*(2):88–99.

Gianessi, L. P. (2013). The increasing importance of herbicides in worldwide crop production. *Pest management science*, *69*(10), 1099-1105.

Giles, D. K., Akesson, N. B., & Yates, W. E. (2008). Pesticide application technology: research and development and the growth of the industry. *Transactions of the ASABE*, *51*(2), 397-403.

Goh, Y. K., Lai, C. H., Mahamooth, T. N., & Huang, H. (2014). Chemical control of *Mucuna bracteata* DC. Ex Kurz legume cover crop. *Oil Palm Bulletin*, *68*, 16-24.

Goh, Y. K., Wong, K. L., Lai, C. H., Tan, S. Y., & Nazir, T. (2015). Control of *Mucuna bracteata* Dc. Ex. Kurz legume covers with herbicides in oil palm plantation: Spraying volume and frequency. *Oil Palm Bulletin*, *70*, 1-7.

Goh, K. J., Gan, H. H., Ng, P. H. C., & PO, S. B. (2007). Agronomy of *Mucuna bracteata* under oil palm. *Mucuna bracteata*, 45-84.

Gomes, M. P., Smedbol, E., Chalifour, A., Hénault-Ethier, L., Labrecque, M., Lepage, L., ... & Juneau, P. (2014). Alteration of plant physiology by glyphosate and its by-product aminomethylphosphonic acid: an overview. *Journal of Experimental Botany*, 65(17), 4691-4703.

Gorddard, R. J., Pannell, D. J., & Hertzler, G. (1995). An optimal control model for integrated weed management under herbicide resistance. *Australian Journal of Agricultural Economics*, *39*(1), 71-87.

Grandin, T. (2022). Grazing cattle, sheep, and goats are important parts of a sustainable agricultural future. *Animals*, *12*(16), 2092.

Green, J. M. (2014). Current state of herbicides in herbicide-resistant crops. *Pest Management Science*, *70*(9), 1351-1357.

Gustafson, D. I. (2011). Climate change: a crop protection challenge for the twenty-first century. *Pest Management Science*, *67*(6), 691-696.

Guo, S., Li, J., Yao, W., Hu, X., Wei, X., Long, B., ... & Li, H. (2021). Optimization of the factors affecting droplet deposition in rice fields by rotary unmanned aerial vehicles (UAVs). *Precision Agriculture*, *22*(6), 1918-1935.

Hansson, D., & Mattsson, J. E. (2002). Effect of drop size, water flow, wetting agent and water temperature on hot-water weed control. *Crop Protection*, *21*(9), 773-781.

Hassanalian, M., & Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. *Progress in Aerospace Sciences*, *91*, 99-131.

Hager, A. G. (1994). Chapter 12: Weed Management Practices. In *Illinois Agronomy Handbook* (pp. 153-177).

Haggblade, S., Minten, B., Pray, C., Reardon, T., & Zilberman, D. (2017). The herbicide revolution in developing countries: patterns, causes, and implications. *The European Journal of Development Research*, *29*, 533-559.

Harker, K. N., & O'Donovan, J. T. (2013). Recent weed control, weed management, and integrated weed management. *Weed Technology, 27*, 1-11.

Hendra, R., & Hill, A. (2019). Rethinking response rates: new evidence of little relationship between survey response rates and nonresponse bias. *Evaluation Review*, *43*(5), 307-330.

Hewitt, A. J., Solomon, K. R., & Marshall, E. J. P. (2009). Spray droplet size, drift potential, and risks to nontarget organisms from aerially applied glyphosate for coca control in Colombia. *Journal of Toxicology and Environmental Health*, *Part A*, *72*(15-16), 921-929.

Hinkin, T. R. (1998). A brief tutorial on the development of measures for use in survey questionnaires. *Organizational Research Methods*, *1*(1), 104-121.

Hoorman, J. J. (2009). Using cover crops to improve soil and water quality. Lima, Ohio: Agriculture and Natural Resources, The Ohio State University Extension.

Holzner, W., & Numata, M. (Eds.). (2013). Biology and ecology of weeds (Vol. 2). Springer Science & Business Media.

Hussain, M., Farooq, S., Merfield, C., & Jabran, K. (2018). Mechanical weed control. In Non-chemical weed control (pp. 133-155). Academic Press.

Hunter III, J. E., Gannon, T. W., Richardson, R. J., Yelverton, F. H., & Leon, R. G. (2020). Integration of remote-weed mapping and an autonomous spraying unmanned aerial vehicle for site-specific weed management. *Pest Management Science*, *76*(4), 1386-1392.

Ikuenobe, C. E., & Ayeni, A. O. (1998). Herbicidal control of *Chromolaena odorata* in oil palm. *Weed Research (Oxford)*, *38*(6), 397-404.

Ireland-Otto, N., Ciampitti, I. A., Blanks, M. T., Burton Jr, R. O., & Balthazor, T. (2016). Costs of using unmanned aircraft on crop farms. *Journal of ASFMRA*, 130-148.

Islam, N., Rashid, M. M., Pasandideh, F., Ray, B., Moore, S., & Kadel, R. (2021). A review of applications and communication technologies for internet of things (IoT) and unmanned aerial vehicle (UAV) based sustainable smart farming. *Sustainability*, *13*(4), 1821.

Jabit, N. N. M., Aani, S. N. A., Hamdani, M. S. A., Zakaria, N., & Abidin, M. Z. Z. (2022, December). Comparative efficacy between premium and generic herbicide of glufosinate ammonium to control weed species in oil palm plantation. In *IOP Conference Series: Earth and Environmental Science*, 1114(1), 012038. IOP Publishing.

Jabatan Operasi, Penggunan racun rumpai Kumpulan FGVPM, 2022.

Jabatan Operasi, Kos merumput Kumpulan FGVPM, 2022.

Jariani, S. M. J., Rosenani, A. B., Samsuri, A. W., Shukor, A. J., & Ainie, H. K. (2010). Adsorption and desorption of glufosinate ammonium in soils cultivated with oil palm in Malaysia. *Malaysian Journal of Soil Science, 14*(1394-7990), 41-52.

Ji, G., Shi, C., & Xue, M. (2022, December). The Application of Unmanned Aerial Vehicles Data Communication in Agriculture. In 2022 IEEE Conference on Telecommunications, Optics and Computer Science (TOCS) (pp. 1378-1382). IEEE.

Jordan, T., Johnson, B., & Nice, G. (2011). Adjuvants Used with Herbicides: Factors to consider. Weed Science, Purdue University. https://ag. purdue. edu/btny/weedscience/Docu-ments/Adjuvants.

Kamaruddin, R., Abdullah, N., & Ayob, M. A. (2018). Determinants of job satisfaction among Malaysian youth working in the oil palm plantation sector. Journal of Agribusiness in Developing and Emerging Economies.

Kalhapure, A. H., Shete, B. T., & Bodake, P. S. (2013). Integration of chemical and cultural methods for weed management in groundnut. *Indian Journal of Weed Science*, *45*(2), 116-119.

Khuzaimah, Z., Nawi, N. M., Adam, S. N., Kalantar, B., Emeka, O. J., & Ueda, N. (2022). Application and Potential of Drone Technology in Oil Palm Plantation: Potential and Limitations. *Journal of Sensors*.

Krishna, K. R. (2016). Push button agriculture: Robotics, drones, satellite-guided soil and crop management. CRC Press.

Kuan et al. (1991). Record of decision, noxious weed management, amendment to Lolo National Forest Plan. USDA Forest Service, Lolo National Forest, Missoula, MT.

Kudsk, P. (2002). Optimising herbicide performance. *Weed Management Handbook*, *9*, 323-344.

Laporan Penilaian Saringan Racun Kumpulan Perladangan FGV & Felda, 2020-2022.

Latiff, M. R., Arbain, M. A., & CC, C. T. (2009). Efficacy of generic herbicides of glyphosate, glufosinate ammonium and metsulfuron methyl for weed control in oil palm. In *PIPOC International Palm Oil Congress*.

Lal, R. (2004). Carbon emission from farm operations. *Environment international*, 30(7), 981-990.

Lam, C. H., Lim, J. K., & Jantan, B. (1993). Comparative studies of a paraquat mixture and glyphosate and/or its mixtures on weed succession in plantation crops. *Planter*, *69*(812), 525-535.

Lee, L. J., & Ngim, J. (2000). A first report of glyphosate-resistant goosegrass (Eleusine indica (L) Gaertn) in Malaysia. Pest Management Science: formerly Pesticide Science, 56(4), 336-339.

Li, L., Hu, Z., Liu, Q., Yi, T., Han, P., Zhang, R., & Pan, L. (2022). Effect of flight velocity on droplet deposition and drift of combined pesticides sprayed using an unmanned aerial vehicle sprayer in a peach orchard. *Frontiers in Plant Science*, *13*, 981494.

Ling-Hoak, O., Keong-Hoe, L., & Khoon-San, C. (2007). Turning POME and EFB into organic fertilizer without waste and discharge.

Lim, L. J., & Ngim, J. (2000). A first report of glyphosate-resistant goosegrass (*Eleusine indica* (L.) Gaertn) in Malaysia. *Pest Management Science: formerly Pesticide Science*, *56*(4), 336-339.

Li, K., Tscharntke, T., Saintes, B., Buchori, D., & Grass, I. (2019). Critical factors limiting pollination success in oil palm: a systematic review. *Agriculture, Ecosystems & Environment*, *280*, 152-160.

Lou, Z., Xin, F., Han, X., Lan, Y., Duan, T., & Fu, W. (2018). Effect of unmanned aerial vehicle flight height on droplet distribution, drift and control of cotton aphids and spider mites. *Agronomy*, *8*(9), 187.

Lundkvist, A., & Verwijst, T. (2011). Weed biology and weed management in organic farming. *Research in Organic Farming*, 10-41.

Malaysian Rubber Board (MRB). (2010). Kawalan Rumpai Di Kawasan Tanaman Getah. www.lgm.gov.my.

Malaysia Palm Oil Board (MPOB). (2014). www.mpob.gov.my.

Malaysia Palm Oil Board (MPOB), Ministry of plantation and commodities. (2022). www.mpob.gov.my.

Malaysian Palm Oil Association (MPOA) approved foreign workers met only 19% of oil palm plantation sector's requirement in 2022.

Malaysian Oil Palm Council (MPOC). (2016). https://mpoc.org.my.

Manual Ladang Sawit Lestari, FGV. (2018). Edisi 3.

Magarey, R. D., Klammer, S. S., Chappell, T. M., Trexler, C. M., Pallipparambil, G. R., & Hain, E. F. (2019). Eco-efficiency as a strategy for optimizing the sustainability of pest management. *Pest Management Science*, *75*(12), 3129-3134.

Macé, K., Morlon, P., Munier-Jolain, N., & Quéré, L. (2007). Time scales as a factor in decision-making by French planters on weed management in annual crops. *Agricultural Systems*, *93*(1-3), 115-142.

Malmqvist, J., Hellberg, K., Möllås, G., Rose, R., & Shevlin, M. (2019). Conducting the pilot study: A neglected part of the research process? Methodological findings supporting the importance of piloting in qualitative research studies. *International Journal of Qualitative Methods*, *18*, 1609406919878341. Matthews, G., Bateman, R., & Miller, P. (2014). Pesticide application methods. John Wiley & Sons.

Martinez-Guanter, J., Agüera, P., Agüera, J., & Pérez-Ruiz, M. (2020). Spray and economics assessment of a UAV-based ultra-low-volume application in olive and citrus orchards. *Precision Agriculture*, *21*(1), 226-243.

McFalls, J., Yi, Y. J., Li, M. H., Senseman, S., & Storey, B. (2015). Evaluation of generic and branded herbicides: technical report.

McMullan, P. M. (2000). Utility adjuvants. *Weed Technology*, *14*(4), 792-797.

McGiffen Jr, M. E., Shrestha, A., & Fennimore, S. A. (2014). Chemical control methods. *Principles of Weed Control. Edition: Fourth, Chapter: Chemical Control Methods, California Weed Science Society, Fennimore, SA & Bell CA (eds)*, 89-133.

Memon, M. S., Shaikh, S. A., Shaikh, A. R., Fahim, M. F., N Mumtaz, S., & Ahmed, N. (2015). An assessment of knowledge, attitude and practices (KAP) towards diabetes and diabetic retinopathy in a suburban town of Karachi. *Pakistan Journal of Medical Sciences*, *31*(1), 183–188. https://doi.org/10.12669/pjms.311.6317

Menalled, F. (2009). Integrated weed management in lentils. Bozeman, MT: Montana State University Extension MontGuide MT201009AG.

Mesnage, R., Benbrook, C., & Antoniou, M. N. (2019). Insight into the confusion over surfactant co-formulants in glyphosate-based herbicides. *Food and Chemical Toxicology*, *128*, 137-145.

Mitku, G. (2021). Generic pesticide understanding by small holder planters in Fogera District, South Gondar Ethiopia. *Asian Journal of Advances in Research*, 205-209.

Ministry of Plantation Industries and Commodities, 2022.

Mogili, U. R., & Deepak, B. B. V. L. (2018). Review on application of drone systems in precision agriculture. *Procedia Computer Science*, *133*, 502-509.

Mohamad, R. Wibawa, W., Mohayidin, M.G., Puteh, A., Juraimi, A.S., A.S., Awang, Y., & Mohd Lassim, M. (2010). Management of mixed weeds in young oil-palm plantation with selected broad-spectrum herbicides. *Pertanika Journal of Tropical Agricultural Science, 33*(2), 193-203.

Monaco, T. J., Weller, S. C., & Ashton, F. M. (2002). Weed science: principles and practices. John Wiley & Sons.

Monteiro, A., & Santos, S. (2022). Sustainable approach to weed management: The role of precision weed management. Agronomy, 12(1), 118.

Mortensen, D. A., Bastiaans, L., & Sattin, M. (2000). The role of ecology in the development of weed management systems: an outlook. *Weed Research (Oxford)*, *40*(1), 49-62.

Mukthiyar, S., Kumar, B. V., Varshith, K., & Anandhu, A. (2017). Spraying Herbicides on Weed through Drones. *International Journal of Innovative Research in Science, Engineering and Technology, 6*(9).

Mustafa, I. F., & Hussein, M. Z. (2020). Synthesis and technology of nanoemulsion-based pesticide formulation. *Nanomaterials*, *10*(8), 1608.

Mujawamariya, G., & Kalema, E. (2017). Limited usage of mechanical equipment in small-scale rice farming: a cause for concern. *Journal of Agriculture and Environment for International Development (JAEID)*, *111*(1), 5-21.

Naidu, L., & Moorthy, R. (2021). A review of key sustainability issues in Malaysian palm oil industry. *Sustainability*, *13*(19), 10839.

Nambiappan, B., Ismail, A., Hashim, N., Ismail, N., Shahari, D. N., Idris, N. A. N., ... & Kushairi, A. (2018). Malaysia: 100 years of resilient palm oil economic performance. *Journal of Oil Palm Research*, *30*(1), 13-25.

Nawi, N. M., Yahya, A., Chen, G., Bockari-Gevao, S. M., & Maraseni, T. N. (2012). Human energy expenditure in lowland rice cultivation in Malaysia. *Journal of Agricultural Safety and Health*, *18*(1), 45-56.

Norhidayu, A., Nur-Syazwani, M., Radzil, R., Amin, I., & Balu, N. (2017). The production of crude palm oil in Malaysia. *International Journal of Economics and Management*, *11*(3), 591-606.

Norman, K., Ramle, M., Saharul, A. M., & Mohd, R. S. (2018). Fruit set and weevil pollination issues in oil palm. *Planter*, *94*(1110), 565-578.

Norsworthy, J. K., Ward, S. M., Shaw, D. R., Llewellyn, R. S., Nichols, R. L., Webster, T. M., ... & Barrett, M. (2012). Reducing the risks of herbicide resistance: best management practices and recommendations. *Weed Science, 60*(SP1), 31-62.

Nulty, D. D. (2008). The adequacy of response rates to online and paper surveys: what can be done? *Assessment & Evaluation in Higher Education*, *33*(3), 301-314.

OECD, F.A.O. (2022). OECD-FAO Agricultural Outlook 2022-2031.

Oerke, E. C. (2006). Crop losses to pests. *The Journal of Agricultural Science*, *144*(1), 31-43.

Ofosu-Budu, K. G., Avaala, S. A., Zutah, V. T., & Baafi, J. (2014). Effect of glyphosate on weed control and growth of oil palm at immature stage in Ghana. *International Journal of Agronomy and Agricultural Research (IJAAR), 4*(4), 1-8.

Orson, J. H., Thomas, M. R., & Kudsk, P. (2001). Impact of generic herbicides on current and future weed problems and crop management. In *Brighton Crop Protection Conference Weeds* (Vol. 1, pp. 123-134).

Orme, A. (2001). Evolving a New Estate Practice for Circle and Path Spraying. *Aventis Cropscience, Essex, UK.*

Othman, W., & Wan, H. (2011). Land preparation practices for oil palm replanting-Sawit Kinabalu group's experience in Sabah. *Planter, 87*(1019), 105-119.

Owen, M. D. (2016). Diverse approaches to herbicide-resistant weed management. *Weed Science, 64*(S1), 570-584.

Özen, E. (2019). *Design of unmanned aerial vehicle and ground terminal* (Master's thesis). Fen Bilimleri Enstitüsü.

Pacanoski, Z. (2015). Herbicides and adjuvants. In A. Price, J. Kelton, & L. Sarunaite (Eds.), *Herbicides, Physiology of Action, and Safety* (pp. 125-147). InTechOpen.

Patterson, D. T. (1995). Weeds in a changing climate. *Weed Science, 43*(4), 685-700.

Parveez, G. K. A., Hishamuddin, E., Loh, S. K., Ong-Abdullah, M., Salleh, K. M., Bidin, M. N. I. Z., ... & Idris, Z. (2020). Oil palm economic performance in Malaysia and R&D progress in 2019. *Journal of Oil Palm Research, 32*(2), 159-190.

Personal communication, Jengka, Pahang FGV, Mac 2020.

Phillips, R. L., & Ormsby, R. (2016). Industry classification schemes: An analysis and review. *Journal of Business & Finance Librarianship, 21*(1), 1-25.

Pieterse, P. J. (2010). Herbicide resistance in weeds–a threat to effective chemical weed control in South Africa. *South African Journal of Plant and Soil, 27*(1), 66-73.

Piola, L., Fuchs, J., Oneto, M. L., Basack, S., Kesten, E., & Casabé, N. (2013). Comparative toxicity of two glyphosate-based formulations to *Eisenia andrei* under laboratory conditions. *Chemosphere, 91*(4), 545-551.

Powles, S. B., Preston, C., Bryan, I. B., & Jutsum, A. R. (1997). Herbicide resistance: Impact and management. *Advances in Agronomy, 58*, 57-93.

PT Pandawa Agri. (2020). https://pandawaid.com/id/halaman-utama.

Putri, P. H., & Guntoro, D. (2018). Effectiveness of WEED Solut-ioN® as herbicide adjuvant to control weeds in oil palm plantations. In *IOP Conference Series: Earth and Environmental Science*, 183(1), p. 012022. IOP Publishing.

Qasem, J. R. (2011). Herbicides applications: problems and considerations. In *Herbicides and environment*. IntechOpen.

Qin, W., Xue, X., Zhang, S., Gu, W., & Wang, B. (2018). Droplet deposition and efficiency of fungicides sprayed with small UAV against wheat powdery mildew. *International Journal of Agricultural and Biological Engineering, 11*(2), 27-32.

Qin, W. C., Qiu, B. J., Xue, X. Y., Chen, C., Xu, Z. F., & Zhou, Q. Q. (2016). Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. *Crop Protection, 85*, 79-88.

Rana, S. S., & Rana, M. C. (2016). Principles and practices of weed management. *Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 138*.

Rasmussen, J., Nielsen, J., Garcia-Ruiz, F., Christensen, S., & Streibig, J. C. (2013). Potential uses of small, unmanned aircraft systems (UAS) in weed research. *Weed research, 53*(4), 242-248.

Radosevich, S. R., Holt, J. S., & Ghersa, C. (1997). *Weed ecology: implications for management*. John Wiley & Sons.

Reade, J. P., & Cobb, A. H. (2002). Herbicides: modes of action and metabolism. *Weed management handbook, 9*, 134-170.

Roussos, P. A., Ntanos, E., Denaxa, N. K., Tsafouros, A., Bouali, I., Nikolakakos, V., & Assimakopoulou, A. (2021). Auxin (triclopyr) and cytokinin (forchlorfenuron) differentially affect fruit physiological, organoleptic and phytochemical properties of two apricot cultivars. *Acta Physiologiae Plantarum*, *43*, 1-12.

Rosli, A. (2000). Guidelines on Cattle Integration in Oil Palm Plantation. Manual for Planters, 2-17.

Roberts, E. S. (1999). In defence of the survey method: An illustration from a study of user information satisfaction. *Accounting & Finance, 39*(1), 53-77.

Rutherford, M., Lamontagne-Godwin, J., Varia, S., Seier, M., Flood, J., & Sastroutomo. S.S. (2009). Review of Literature on the toxicity and environmental and ecological fate of herbicides commonly used in oil palm cultivation. In *Final report: Roundtable for Sustainable Palm Oil (RSPO). Research project on integrated weed management strategies for oil palm*, 13-91.

Rutherford, M., Flood, J., & Sastroutomo, S. S. (2011). Final Report: Roundtable for Sustainable Palm Oil (RSPO): Research project on Integrated Weed Management Strategies for Oil Palm. *Final report, 209,* 205.

Rutherford, M., Flood, J. & S Sastroutomo, S. (2011). Part 6. Overall summary and concluding points. In *Final report: Roundtable for Sustainable Palm Oil (RSPO). Research project on integrated weed management strategies for oil palm*, 1-186.

Ruslan, K. A. C., & Hamdani, M. S. A. (2021). Integrated weed management programs at oil palm plantation-A Survey. *International Journal of Agriculture, Forestry and Plantation, 11,* 32-38.

Ryan, P. (2002). The impact of generic herbicides on crop protection. *Pesticide Outlook*, *13*(1), 35-39.

Sangeeta, & Tandon, U. (2021). Factors influencing adoption of online teaching by school teachers: A study during COVID‐19 pandemic. *Journal of Public Affairs*, *21*(4), e2503.

Santos-Sánchez, N. F., Salas-Coronado, R., Hernández-Carlos, B., & Villanueva-Cañongo, C. (2019). Shikimic acid pathway in biosynthesis of phenolic compounds. *Plant Physiological Aspects of Phenolic Compounds*, *1*, 1-15.

Sardana, V., Mahajan, G., Jabran, K., & Chauhan, B. S. (2017). Role of competition in managing weeds: An introduction to the special issue. *Crop Protection*, *95*, 1-7.

Samedani, B., Juraimi, A. S., Rafii, M. Y., Sheikh Awadz, S. A., Anwar, M. P., & Anuar, A. R. (2015). Effect of cover crops on weed suppression in oil palm plantation. *International Journal of Agriculture and Biology, 17*(2), 251-260.

Shaner, D. L., & Beckie, H. J. (2014). The future for weed control and technology. *Pest Management Science, 70*, 1329-1339.

Shan, C., Wang, G., Wang, H., Xie, Y., Wang, H., Wang, S., ... & Lan, Y. (2021). Effects of droplet size and spray volume parameters on droplet deposition of wheat herbicide application by using UAV. *International Journal of Agricultural and Biological Engineering*, 14(1), 74-81.

Shaner, D. L. (2014). Lessons learned from the history of herbicide resistance. *Weed Science, 62,* 427-431.

Singh, B. K., & Shaner, D. L. (1998). Rapid determination of glyphosate injury to plants and identification of glyphosate-resistant plants. *Weed Technology*, *12*(3), 527-530.

Soon, C. P., Joo, G. K., & Huang, G. H. (1999). An AAR Update On The Malaysian Oil Palm Industry Low OER Problems.

Stedman, R. C., Connelly, N. A., Heberlein, T. A., Decker, D. J., & Allred, S. B. (2019). The end of the (research) world as we know it? Understanding and coping with declining response rates to mail surveys. *Society & Natural Resources*, *32*(10), 1139-1154.

Structural formula of Metsulfuron methyl. Retrieved from https://pubchem.ncbi.nlm.nih.gov/compound/Metsulfuron-methyl

Structural formula of Triclopyr butoxy ethyl ester. Retrieved from https://www.gharda.com/triclopyr-butoxy-ethyl-ester

Surgan, M., Condon, M., & Cox, C. (2010). Pesticide risk indicators: unidentified inert ingredients compromise their integrity and utility. *Environmental Management*, *45*(4), 834-841.

Su, A. S. M., Yahya, A., Mazlan, N., & Hamdani, M. S. A. (2018). Evaluation of the Spraying Dispersion and Uniformity Using Drone in Rice. Paper presented at the 2018 MSAE Conference, Serdang, Selangor.

Sun, F., Wang, X., & Zhang, R. (2020). Task scheduling system for UAV operations in agricultural plant protection environment. *Journal of Ambient Intelligence and Humanized Computing*, 1-15.

Swaray, S., Y. Rafii, M., Din Amiruddin, M., Firdaus Ismail, M., Jamian, S., Jalloh, M., ... & Chukwu, S. C. (2021). Assessment of oil palm pollinating weevil (*Elaeidobius kamerunicus*) population density in biparental *Dura* × *Pisifera* hybrids on deep peat-soil in Perak state, Malaysia. *Insects*, *12*(3), 221.

Taddei, M., Donnadio, A., Costantino, F., Vivani, R., & Casciola, M. (2013). Synthesis, crystal structure, and proton conductivity of one-dimensional, two-dimensional, and three-dimensional zirconium phosphonates based on glyphosate and glyphosine. *Inorganic Chemistry*, *52*(20), 12131-12139.

Tang, Y., Dananjayan, S., Hou, C., Guo, Q., Luo, S., & He, Y. (2021). A survey on the 5G network and its impact on agriculture: Challenges and opportunities. *Computers and Electronics in Agriculture*, *180*, 105895.

Tapia, J. F. D., Doliente, S. S., & Samsatli, S. (2021). How much land is available for sustainable palm oil? *Land Use Policy*, *102*, 105187.

Tao, B., Zhou, J., Messersmith, C. G., & Nalewaja, J. D. (2007). Efficacy of glyphosate plus bentazon or quizalofop on glyphosate-resistant canola or corn. *Weed Technology*, *21*(1), 97-101.

Takano, H. K., & Dayan, F. E. (2020). Glufosinate-ammonium: a review of the current state of knowledge. *Pest Management Science*, *76*(12), 3911-3925.

Tabachnick, B. G., & Fidell, L. S. (2007). Experimental designs using ANOVA (Vol. 724). Belmont, CA: Thomson/Brooks/Cole.

Teo, T. M. (2015). Effectiveness of the oil palm pollinating weevil, *Elaeidobius kamerunicus*, in Malaysia.

Telkar, S. G., Gurjar, G. N., Dey, J. K., Kant, K., & Solanki, S. P. S. (2015). Biological weed control for sustainable agriculture. International Journal of Economic Plants, 2(4), 181-183.

Third National Agricultural Policy (1998-2010), https://www.fama.gov.my/en/dasar-pertanian-negara-ketiga-dpn3.

Thongjua, J., & Thongjua, T. (2016). Effect of herbicides on weed control and plant growth in immature oil palm in the wet season Nakhon Si Thammarat, Thailand. *International Journal of Agricultural Technology*, *12(*7.1), 1385-1396.

Tominack, R. L., & Tominack, R. (2000). Herbicide formulations. *Journal of Toxicology: Clinical Toxicology, 38*(2), 129-135.

Tohiran, K. A., Nobilly, F., Zulkifli, R., Maxwell, T., Moslim, R., & Azhar, B. (2017). Targeted cattle grazing as an alternative to herbicides for controlling weeds in bird-friendly oil palm plantations. *Agronomy for Sustainable Development, 37*, 1-11.

Tu, M., & Randall, J. M. (2003) Adjuvants. In *Weed Control Methods Handbook. The Nature Conservancy*. TNC, Davis, CA; 2003. Pp. 1–24.

Turner, P. D., & Gillbanks, R. A. (2003). Oil Palm Cultivation and Management. Kuala Lumpur: The Incorporated Society of Planters.

Turner, P. D., & Gillbanks, R. A. (1974). Oil palm cultivation and management. *Oil Palm Cultivation and Management.*

Uludag, A., Uremis, I., & Arslan, M. (2018). Biological weed control. In Non-chemical weed control (pp. 115-132). Academic Press.

Unpublished data, Closure report Weed Solution, FGV. (2021).

Ustidivanissa, F. L., Njatrijani, R., & Pramono, A. (2017). Tinjauan Yuridis Pengoperasian Pesawat Tanpa Awak Terhadap Keselamatan Penerbangan di Wilayah Negara Kesatuan Republik Indonesia (Studi Pada PT. Uavindo Nusantara, Bandung). *Diponegoro Law Journal, 6*(2), 1-14.

Urach Ferreira, P. H., Ferguson, J. C., Reynolds, D. B., Kruger, G. R., & Irby, J. T. (2021). Crop residue and rainfall timing effect on pre-emergence herbicides efficacy using different spray nozzle types. *International Journal of Pest Management*, 1-11.

Vakhterova, Y. V., Avdeeva, L. V., Zimens, M. E., Shvydkii, V. O., Machigov, E. A., Lebedev, A. T., ... & Saratovskikh, E. A (2023). *Sustainable Chemistry and Pharmacy 32*, 100957.

Vanhala, P., Kurstjens, D. A. G., Ascard, J., Bertram, A., & Cloutier, D. (2004). Guidelines for physical weed control research: flame weeding, weed harrowing and intra-row cultivation. In *Proceedings 6th EWRS Workshop on Physical and Cultural Weed Control* (pp. 194-225).

Van den Broeck, J., Argeseanu Cunningham, S., Eeckels, R., & Herbst, K. (2005). Data cleaning: detecting, diagnosing, and editing data abnormalities. *PloS Medicine*, 2(10), e267.

Vencill, W. K., Nichols, R. L., Webster, T. M., Soteres, J. K., Mallory-Smith, C., Burgos, N. R., ... & McClelland, M. R. (2012). Herbicide resistance: toward an understanding of resistance development and the impact of herbicide-resistant crops. *Weed Science, 60*(SP1), 2-30.

Velini, E., Duke, S., Trindade, M. L., Meschede, D., & Carbonari, C. (2009). Mode of Action of Glyphosate. *DK Meschede, CA Carbonari and MLB Trindade (Eds.). FEPAF, Botucatu*, 113-134.

Velini, E. D. I. V. A. L. D. O., Duke, S. O., Trindade, M. L. B., Meschede, D. K., & Carbonari, C. A. (2009). Mode of action of glyphosate. *USDA: Washington, DC, USA*, 113-134.

Villamayor Jr, F. G., & Reoma, V. L. (1987). Effects of land preparation and postplanting tillage on weed control and cassava yield. *Annals of Tropical Research (Philippines)*.

Walker, R. H. (2017). Preventive weed management. In Handbook of weed management systems (pp. 35-50). Routledge.

Wan Mohamed et al. (1987). International survey of herbicide resistant weeds. Dr. Ian Heap, P.O. Box 1365, Corvallis, Oregon. http://www.weedscience.com [4 Feb 99].

Ward, B. (2010). Cost Saving Ideas and Innovations in Crop Production, Ohio State University AEDE.

Wang, G., Lan, Y., Qi, H., Chen, P., Hewitt, A., & Han, Y. (2019). Field evaluation of an unmanned aerial vehicle (UAV) sprayer: effect of spray volume on deposition and the control of pests and disease in wheat. *Pest Management Science*, *75*(6), 1546-1555.

Wang, J., Lan, Y., Wen, S., Hewitt, A. J., Yao, W., & Chen, P. (2020). Meteorological and flight altitude effects on deposition, penetration, and drift in pineapple aerial spraying. *Asia-Pacific Journal of Chemical Engineering, 15*(1), e2382.

Wang, G., Han, Y., Li, X., Andaloro, J., Chen, P., Hoffmann, W. C., ... & Lan, Y. (2020). Field evaluation of spray drift and environmental impact using an agricultural unmanned aerial vehicle (UAV) sprayer. *Science of the Total Environment*, *737*, 139793.

Wang, L., Huang, X., Li, W., Yan, K., Han, Y., Zhang, Y., ... & Lan, Y. (2022). Progress in agricultural unmanned aerial vehicles (UAVs) applied in China and prospects for Poland. *Agriculture, 12*(3), 397.

Wang, Z., Lan, L., He, X., & Herbst, A. (2020). Dynamic evaporation of droplet with adjuvants under different environment conditions. *International Journal of Agricultural and Biological Engineering*, *13*(2), 1-6.

Wen, S., Zhang, Q., Yin, X., Lan, Y., Zhang, J., & Ge, Y. (2019). Design of plant protection UAV variable spray system based on neural networks. *Sensors, 19*(5), 1112.

Weng, C. K. (2005). Best-developed practices and sustainable development of the oil palm industry. *Journal of Oil Palm Research, 17*, 124.

Weis, M., Gutjahr, C., Ayala, V. R., Gerhards, R., Ritter, C., & Schölderle, F. (2008). Precision farming for weed management: techniques. *Gesunde Pflanzen, 60*(4), 171.

Westwood, J. H., Charudattan, R., Duke, S. O., Fennimore, S. A., Marrone, P., Slaughter, D. C., ... & Zollinger, R. (2018). Weed management in 2050: Perspectives on the future of weed science. *Weed science, 66*(3), 275-285.

Wibawa, W., Mohamad, R., Juraimi, A. S., Omar, D., Ghazali Mohayidin, M., & Begum, M. (2009). Weed control efficacy and short term weed dynamic impact of three Non-selective herbicides in immature oil palm plantation. *International Journal of Agriculture and Biology, 11*, 145150.

Wibawa, W., Mohammad, R., Omar, D., & Juraimi, A. S. (2007). Less hazardous alternative herbicides to control weeds in immature oil palm. *Weed Biology and Management*, *7*, 242-247.

Wibawa, W., Mohayidin, M. G., Mohamad, R. B., Juraimi, A. S., & Omar, D. (2010). Efficacy and cost-effectiveness of three broad-spectrum herbicides to control weeds in immature oil palm plantation. Pertanika Journal of Tropical Agricultural Science, 33(2), 233-241.

Wibawa, W., Mohamad, R., & Omar, D. (2005). Cost-effective of three broad-spectrum herbicides in immature area oil palm. *Herbicides in Perspective, 68*, 45-48.

Woodward, K. N. (2008). Assessment of user safety, exposure and risk to veterinary medicinal products in the European Union. *Regulatory Toxicology and Pharmacology, 50*(1), 114-128.

Wong P. W. (1981). Tolerance of young oil palm to glyphosate. In Proceedings of the International Conference on Oil Palm in Agriculture in the Eighties, Pushparajah, E. Chew, P.S. (eds.), Kuala Lumpur (Malaysia): PPP (ISP), 1982. (p. 329-335).

Wulandari, R., Lotrakul, P., Punnapayak, H., Amirta, R., Kim, S. W., & Prasongsuk, S. (2021). Toxicity evaluation and biodegradation of phenanthrene by laccase from *Trametes polyzona* PBURU 12. 3. *Biotech, 11*, 1-11.

Xiao, Q., Xin, F., Lou, Z., Zhou, T., Wang, G., Han, X., & Fu, W. (2019). Effect of aviation spray adjuvants on defoliant droplet deposition and cotton defoliation efficacy sprayed by unmanned aerial vehicles. *Agronomy, 9*(5), 217.

Xiao, Q., Du, R., Yang, L., Han, X., Zhao, S., Zhang, G., Wang & Lan, Y. (2020). Comparison of droplet deposition control efficacy on phytophthora capsica and aphids in the processing pepper field of the unmanned aerial vehicle and knapsack sprayer. *Agronomy, 10*(2), 215.

Xiongkui, H., Bonds, J., Herbst, A., & Langenakens, J. (2017). Recent development of unmanned aerial vehicle for plant protection in East Asia. *International Journal of Agricultural and Biological Engineering, 10*(3), 18-30.

Xue, X., Zeng, K., Li, N., Luo, Q., Ji, Y., Li, Z., ... & Song, S. (2023). Parameters Optimization and Performance Evaluation Model of Air-Assisted Electrostatic Sprayer for Citrus Orchards. *Agriculture, 13*(8), 1498.

Yap, P., Rosdin, R., Abdul-Rahman, A. A. A., Omar, A. T., Mohamed, M. N., & Rahami, M. S. (2021). Malaysian Sustainable Palm Oil (MSPO) Certification Progress for Independent Smallholders in Malaysia. In *IOP Conference Series: Earth and Environmental Sci*ence, 736(1), 012071. IOP Publishing.

Yousefi, M., Rafie, A. S. M., Abd Aziz, S., & Azrad, S. (2020). Introduction of current pollination techniques and factors affecting pollination effectiveness by *Elaeidobius kamerunicus* in oil palm plantations on regional and global scale: A review. *South African Journal of Botany, 132*, 171-179.

Zamri-Saad, M., & Azhar, K. (2015). Issues of ruminant integration with oil palm plantation. *Journal of Oil Palm Research, 27*(4), 299-305.

Zhu, H., Salyani, M., & Fox, R. D. (2011). A portable scanning system for evaluation of spray deposit distribution. *Computers and Electronics in Agriculture, 76*(1), 38-43.

Zhang Y, Slaughter, D. C., & Staab, E. S. (2012). Robust hyperspectral vision-based classification for multi-season weed mapping. *ISPRS Journal Photogrammetry Remote Sensing, 69,* 65–73.

Zimdahl, R. L. (2007). Weed-crop competition: a review.

Zulkefli, F., Syahlan, S., Bakar, M. A., Khalid, M. F., & Rakibe, I. (2020). Factors influencing labour productivity in oil palm estate. *International Journal of Academic Research in Business and Social Sciences, 10*(4), 119-131.