

**CHARACTERIZATION OF SOIL TREATED AND
OPTIMIZATION STUDIES ON AB MIX
NUTRIENTS USAGE TOWARDS CAPSICUM
FRUTESCENS**

NUR DINIE SYAHIRAH BINTI SANUSI

**MASTER OF SCIENCE
(PHYSICS)**

**UNIVERSITI PERTAHANAN NASIONAL
MALAYSIA**

2024

**CHARACTERIZATION OF SOIL TREATED AND OPTIMIZATION
STUDIES ON AB MIX NUTRIENTS USAGE TOWARDS CAPSICUM
FRUTESCENS**

NUR DINIE SYAHIRAH BINTI SANUSI

Thesis submitted to the Centre for Graduate Studies, Universiti Pertahanan Nasional
Malaysia, in fulfilment of the requirements for the Degree of Master of Science
(Physics)

2024

ABSTRACT

This thesis investigates the characterization of soil treated with AB mix nutrients and the optimization of its usage towards *Capsicum frutescens* (*C. frutescens*) cultivation. Driven by the need to address the environmental issues arising from excessive fertilizer usage that exceeds recommended guidelines, this study aims to determine optimal nutrient application rates that are environmentally sustainable while maintaining agricultural productivity. Employing characterization techniques such as Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES), Energy-Dispersive X-Ray Fluorescence (EDXRF) and Vector Network Analysis (VNA), the research identifies elemental composition and evaluates soil dielectric properties. EDXRF analysis revealed significant detection of elements spectrum in the soil at different energy ranges; the several elements detected were aluminium (Al), sulphur (S) and chlorine (Cl), where the element intensities observed vary with the electrical conductivity (EC) levels of AB mix nutrient. This analysis provided detailed elemental composition of the soil, revealing notable increases in elements such as aluminium (Al), which was detected at 2227.105 cps/mA at the lowest EC value, 1.4 mS/cm to 3031.773 cps/mA at 3.5 mS/cm. The highest dielectric constant, ϵ' of the soil sample was observed at 1.4 mS/cm with 6 mL of AB mix nutrients, with the value of 2.2 mS/cm, whilst the lowest dielectric constant, ϵ' was recorded by the controlled sample with ~ 1.1208 . As for the VNA measurements, results showed that higher applications of nutrients generally resulted in lower S -parameter values (S_{11} and S_{21}), reflecting changes in the soil's electromagnetic properties due to varying nutrient concentrations. As the X-band frequency increased, the real and imaginary parts of S -parameters

demonstrated distinct trends. The real S_{11} (reflection coefficient) and S_{21} (transmission coefficient) typically decreased with the increasing frequency, f indicating reduction in signal reflection and transmission efficiency as the nutrient concentration increased. Conversely, the imaginary parts of S -parameters showed variations that suggest complex interactions between the electromagnetic waves and the soil's physical properties, reflecting changes in the soil's dielectric constant, ϵ' . For further understanding on AB mix nutrients concentration effect towards the *C. frutescens* growth, Response Surface Methodology software (RSM) was employed. Result showed that the optimal conditions of the AB mix nutrients for *C. frutescens* were recorded at the concentration of 2.54 mS/cm of AB mix nutrients and the wick length of 18.15 cm. Under these conditions, the maximum plant's height simulated using Analysis of Variance (ANOVA) and RSM was 38.73 cm, which was comparable with the experimental result that recorded 40.2 cm as the maximum height. In short, this research provides an understanding of AB mix nutrient properties, the interaction of nutrients on soil with the microwave frequency, f and the optimum condition of *C. frutescens* growth using fertigation Nutri-pot system. These findings highlight the importance of good fertilizer practices that adapt to specific soil characteristics, promoting sustainable agriculture by optimizing fertilizer use, thereby reducing environmental impact and supporting effective crop growth.

ABSTRAK

Tesis ini mengkaji pencirian tanah yang dirawat dengan nutrisi campuran AB dan pengoptimuman penggunaannya untuk penanaman *Capsicum frutescens* (*C. frutescens*). Berpandukan keperluan untuk mengatasi isu-isu alam sekitar yang timbul daripada penggunaan baja yang berlebihan melebihi garis panduan yang disyorkan, kajian ini bertujuan untuk menentukan kadar penggunaan nutrisi yang optimum yang mesra alam sekitar sambil mengekalkan produktiviti pertanian. Dengan menggunakan teknik pencirian seperti Spektroskopi Emisi Optik - Plasma Berkaitan Induktif (ICP-OES), Pendarfluor Sinar-X Tenaga Serakan (EDXRF) dan Analisis Rangkaian Vektor (VNA), penyelidikan ini mengenal pasti komposisi unsur dan menilai sifat dielektrik tanah. Analisis EDXRF menunjukkan pengesanan yang signifikan bagi unsur-unsur seperti aluminium (Al), sulfur (S) dan klorin (Cl), dengan kepekatan yang berubah dengan tahap kekonduktivitan elektrik (EC) nutrisi campuran AB. Analisis ini memberikan komposisi unsur terperinci tanah, mendedahkan peningkatan ketara dalam unsur seperti aluminium (Al), yang dikesan pada 2227.105 cps/mA pada tahap EC terendah, 1.4 mS/cm kepada 3031.773 cps/mA pada 3.5 mS/cm. Pemalar dielektrik tertinggi, ϵ' sampel tanah diperhatikan pada 1.4 mS/cm dengan 6 mL nutrisi campuran AB, dengan nilai 2.2 mS/cm, manakala pemalar dielektrik terendah, ϵ' dicatatkan oleh sampel kawalan dengan ~ 1.1208 . Bagi pengukuran VNA, hasil menunjukkan bahawa aplikasi nutrisi yang lebih tinggi secara amnya menghasilkan nilai parameter-S (S_{11} dan S_{21}) yang lebih rendah, mencerminkan perubahan dalam sifat elektromagnet tanah akibat variasi kepekatan nutrisi. Apabila frekuensi X-band meningkat, bahagian nyata dan khayalan parameter-S menunjukkan trend yang ketara. S_{11} nyata (pekali pantulan)

dan S_{21} (pekali penghantaran) biasanya menurun dengan peningkatan frekuensi, f menunjukkan pengurangan dalam kecekapan pantulan dan penghantaran isyarat apabila kepekatan nutrien meningkat. Sebaliknya, bahagian khayalan parameter- S menunjukkan variasi yang mencadangkan interaksi kompleks antara gelombang elektromagnet dan sifat fizikal tanah, mencerminkan perubahan dalam pemalar dielektrik tanah, ϵ' . Untuk pemahaman lanjut mengenai kesan kepekatan nutrien campuran AB terhadap pertumbuhan *C. frutescens*, perisian Kaedah Permukaan Tindak Balas (RSM) digunakan. Hasil menunjukkan bahawa keadaan optimum bagi nutrien campuran AB untuk *C. frutescens* dicatatkan pada kepekatan 2.54 mS/cm nutrien campuran AB dan panjang sumbu 18.15 cm. Di bawah keadaan ini, ketinggian maksimum tumbuhan yang disimulasikan menggunakan Analisis Varians (ANOVA) dan RSM adalah 38.73 cm, yang sebanding dengan hasil eksperimen yang mencatatkan 40.2 cm sebagai ketinggian maksimum. Secara ringkas, kajian ini memberikan pemahaman tentang sifat nutrien campuran AB, interaksi nutrien pada tanah dengan frekuensi gelombang mikro, f dan keadaan optimum pertumbuhan *C. frutescens* menggunakan sistem Nutri-pot fertigasi. Penemuan ini menekankan kepentingan amalan baja yang baik yang disesuaikan dengan ciri-ciri tanah tertentu, mempromosikan pertanian mampan dengan mengoptimumkan penggunaan baja, seterusnya mengurangkan impak terhadap alam sekitar dan menyokong pertumbuhan tanaman yang berkesan.

ACKNOWLEDGEMENTS

In the name of Allah, Most Gracious, Most Merciful. Praise be to Almighty Allah. Alhamdulillah, all praises is due to Allah for His Strength and Blessings in completing this thesis.

Special appreciation goes to my supervisor, Ts. Dr. Fadhlina binti Che Ros, for her unwavering supervision and support. Her invaluable assistance through constructive comments and suggestions throughout the experimental work and thesis writing has been instrumental in the success of this research. I also would like to extend my heartfelt appreciation to my co-supervisors, Prof. Madya Siti Zulaikha binti Ngah Demon and Dr. Ismayadi bin Ismail, for their support and insightful contributions to this research.

My deepest gratitude goes to my late father, Sanusi bin Saryan, and my mother, Rosilawati binti Shahadan, as well as my brother and sister, for their prayers and moral support throughout this journey. Special thanks to my cats for their comforting presence during challenging times. Sincere thanks are also due to my colleagues and friends, as well as the staffs and technicians at Universiti Pertahanan Nasional Malaysia (UPNM), for their advice and moral support, which have encouraged me to persevere in this research endeavor. Last but not least, I am grateful to the E Office Agro Plantation Sdn Bhd for their support in providing materials and guidelines for the experiments conducted during my master's journey.

APPROVAL

The Examination Committee has met on **23 August 2024** to conduct the final examination of **Nur Dinie Syahirah binti Sanusi** on his degree thesis entitled **‘Characterization of Soil Treated and Optimization Studies On AB Mix Nutrients Usage Towards *Capsicum Frutescens*’** .

The committee recommends that the student be awarded the of Master of Science (Physics).

Members of the Examination Committee were as follows.

Dr Mohd Syazwan bin Mohamad

Centre For Defense Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Chairman)

Dr Azuraida binti Amat

Centre For Defense Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Dr Nurul Huda binti Osman

Faculty of Science
Universiti Putra Malaysia
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Physics)**. The members of the Supervisory Committee were as follows.

Ts Dr Fadhlina binti Che Ros

Centre For Defense Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Main Supervisor)

Prof Madya Siti Zulaikha binti Ngah Demon

Centre For Defense Foundation Studies
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Dr Ismayadi bin Ismail

Institute of Nanoscience and Nanotechnology
Universiti Putra Malaysia
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name : Nur Dinie Syahirah binti Sanusi
Date of birth : 28 September 1997
Title : Characterization of Soil Treated and Optimization Studies on
AB Mix Nutrients Usage Towards *Capsicum Frutescens*
Academic session : 2024/2025

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

I further declare that this thesis is classified as:

CONFIDENTIAL (Contains confidential information under the official Secret Act 1972)*

RESTRICTED (Contains restricted information as specified by the organisation where research was done)*

OPEN ACCESS I agree that my thesis to be published as online open access (full text)

I acknowledge that Universiti Pertahanan Nasional Malaysia reserves the right as follows.

1. The thesis is the property of Universiti Pertahanan Nasional Malaysia.
2. The library of Universiti Pertahanan Nasional Malaysia has the right to make copies for the purpose of research only.
3. The library has the right to make copies of the thesis for academic exchange.

Signature

970928-14-6494

IC/Passport No.

**Signature of Supervisor/Dean of CGS

Ts Dr Fadhlina binti Che Ros

**Name of Supervisor/Dean of CGS

Date:

Date:

*If the thesis is CONFIDENTIAL OR RESTRICTED, please attach the letter from the organisation with period and reasons for confidentiality and restriction.

** Witness

TABLE OF CONTENTS

	TITLE	PAGE
	ABSTRACT	ii
	ABSTRAK	iv
	ACKNOWLEDGEMENTS	vi
	APPROVAL	vii
	APPROVAL	viii
	DECLARATION OF THESIS	ix
	TABLE OF CONTENTS	x
	LIST OF TABLES	xiii
	LIST OF FIGURES	xv
	LIST OF ABBREVIATIONS	xx
	LIST OF SYMBOLS	xxi
	LIST OF APPENDICES	xxii
CHAPTER 1	INTRODUCTION	1
	1.1 Introduction to Fertilizers	1
	1.2 Survey on the Application Pattern of AB Mix Nutrients amongst the Local Farmers	4
	1.3 <i>Capsicum frutescens</i>	6
	1.4 Problem Statements	8
	1.5 Scope and Limitation of the Study	9
	1.6 Research Objectives	10
	1.7 Significance of Research	11
	1.8 Thesis Overview	11
CHAPTER 2	LITERATURE REVIEW	14
	2.1 Research Theory	14
	2.1.1 Soil Moisture Measurement	14
	2.1.2 Waveguide Transmission / Reflection Method	16
	2.1.3 Introduction to X-Ray	19
	2.1.4 Response Surface Methodology (RSM)	23
	2.2 Urban Farming	26
	2.2.1 Hydroponic	27
	2.2.2 Aquaponic	29
	2.2.3 Aeroponic	29
	2.2.4 Vertical Farming	30
	2.3 Mechanism of Nutrient Uptake in Plants	31
	2.4 Introduction to AB Mix Nutrients	33
	2.5 The Usage of AB Mix Nutrients	36
	2.5.1 AB Mix Nutrients Effect Towards Leafy Vegetables	36

	2.5.2 Combination Effect of AB Mix Nutrients with Other Organic Fertilizer	39
	2.6 Optimization Studies using Response Surface Methodology (RSM) for Plant Growth	45
	2.7 Studies on Dielectric Properties of Soil	53
CHAPTER 3	RESEARCH METHODOLOGY	62
	3.1 Introduction	62
	3.2 Materials and Equipment	62
	3.2.1 Preparation of AB Mix Nutrients	63
	3.2.2 Preparation of Nutri-Pot	65
	3.3 Leaching Test	69
	3.4 Sample Preparation for Soil Analysis	71
	3.4.1 Sample Preparation for Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES)	71
	3.4.2 Sample Preparation for Energy Dispersive X-Ray Fluorescence (EDXRF) and Vector Network Analysis (VNA)	72
	3.5 Experimental Design for Response Surface Methodology, (RSM) Procedure	75
	3.5.1 Statistical Analysis	78
	3.6 Characterization Study	83
	3.6.1 Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES)	83
	3.6.2 Energy Dispersive X-Ray Fluorescence (EDXRF)	84
	3.6.3 Measurement of Soil Dielectric Constant, ϵ' using Vector Network Analyzer, (VNA) via Microwave Non-Destructive Testing, (MNDT)	85
CHAPTER 4	RESULTS AND DISCUSSIONS	87
	4.1 Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES)	87
	4.1.1 AB Mix Nutrients Analysis	87
	4.1.2 Soil Composition Analysis	90
	4.2 Energy Dispersive X-Ray Fluorescence (EDXRF) Analysis	92
	4.2.1 Analysis of AB Mix Nutrients	92
	4.2.2 Analysis of Soil Samples	99
	4.3 Analysis of X-Band Frequency Spectrum using Vector Network Analyzer (VNA)	112
	4.3.1 S-Parameter of Soil Samples	113
	4.3.2 Dielectric Constant, ϵ' of the Soil Samples	133
	4.4 Optimization of AB Mix Nutrients on <i>C.</i> <i>frutescens</i> via Response Surface Methodology (RSM)	137

4.4.1	<i>C. frutescens</i> Growth and Development using Nutri-Pot	137
4.4.2	Optimization Results via Response Surface Methodology (RSM)	148
4.4.3	Graphical Interpretation of RSM and Interaction between Experimental Parameters	155
4.4.4	The Developed Model Adequacy	157
4.4.5	Optimized Condition of AB Mix Nutrients	160
CHAPTER 5	CONCLUSION AND RECOMMENDATIONS	162
5.1	Conclusions	162
5.2	Challenges and Limitation throughout the Research	167
5.3	Future Works and Recommendations	168
	REFERENCES	170
	APPENDICES	182
	BIODATA OF STUDENT	194
	LIST OF PUBLICATIONS	195

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	AB mix nutrients compounds and their functions (Resh, 2013)	35-36
2.2	Types of fertilizer applied and their outcomes on different crops	43-44
2.3	ANOVA for the responses and variables reported by Koocheki et al. (2014)	47
2.4	Summary of optimization techniques used on various crops	52
2.5	Summary of literature reviews in measuring dielectric of soil	61
3.1	Volume of A and B (1:1) (mL) used for required concentration of AB mix nutrients	64-65
3.2	Schedule AB mix nutrients application on <i>C. frutescens</i> plants from Week 1 – Week 7	68
3.3	Quantity of water poured into dry coco-peat and leaking result after 1 hr	69
3.4	The variation of EC value and the amount of AB mix nutrients applied	74
3.5	Range of variables and their coded levels	76
3.6	The coded and actual level of independent variables	76-77
3.7	Operating condition of ICP-OES	84
4.1	Result on the content of AB mix nutrient using ICP-OES	89-90
4.2	Result of the soil test using ICP-OES towards controlled soil samples of different types	92
4.3	List of elements detected by ICP-OES and XRF in AB mix nutrients	93
4.4	Summary of peak intensities for all soil samples using RX-9 and Al targets (cps/mA) with 0 cm soil position as top and 14 cm soil position as bottom	110
4.5	Summary of peak intensities for all soil samples at Al and Mo targets (cps/mA) with 0 cm soil position as top and 14 cm soil position as bottom	111

4.6	Summary of Pearson Correlation analysis of S_{11} amplitude (dB) for control sample and soil samples at EC value ranging 1.4 to 3.5 mS/cm with various amount of application	128
4.7	Summary of Pearson Correlation analysis for S_{11} phase signal (θ) for control sample and soil samples at EC value ranging 1.4 to 3.5 mS/cm with various amount of application	129
4.8	Summary of Pearson Correlation analysis for S_{21} amplitude (dB) for control sample and soil samples at EC value ranging 1.4 to 3.5 mS/cm with various amount of application	130
4.9	Summary of Pearson Correlation analysis for S_{22} Phase (θ) for control sample and soil samples at EC value 1.4 to 3.5 mS/cm with various amount of application	131-132
4.10	Dielectric constant, ϵ' of soil samples with different EC values at 10 GHz. The highlighted column shows the highest dielectric constant, ϵ' value among all soil samples	133
4.11	Range of variables and their coded levels	138
4.12	Experiments designed by Design-Expert software	138
4.13	Variation of EC values, wick lengths and the height of <i>C. frutescens</i> plants in seven weeks	139-141
4.14	Analysis of various models for predicting the response variable	148
4.15	Details of the attempts run using Central Composite Design	151
4.16	Analysis of Variance (ANOVA) for regression model to optimize AB mix nutrients condition	154
4.17	Experimental value versus predicted value of <i>C. frutescens</i> height	159
4.18	Comparison between the actual, predicted and simulated optimized values from RSM for <i>C. frutescens</i> plant	160

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Comparison of EC value vs. weeks from six (6) different respondents	5
1.2	Comparison of total amount of fertilizer applied (L) vs. weeks from six (6) different respondents	6
1.3	The four types of bird's eye chili available in the local market (a) centil, (b) bara, (c) green and (d) siam (Anem, 2021; Diane C., 2023)	7
1.4	Overall workflow of this research	12
2.1	S-parameter representation of a two-port network (Nyikayaramba & Murmann, 2020)	17
2.2	Electromagnetic spectrum – range of frequencies in electromagnetic radiation (Helmenstine, 2023)	19
2.3	Schematic diagram of X-ray fluorescence spectrometer (Rigaku, 2020)	20
2.4	Generation of characteristic radiations (Rigaku, 2020)	21
2.5	Derivation of Bragg's law (Rigaku, 2020)	23
2.6	Three-dimensional response surface and the corresponding contour plot (Draman et al., 2021)	24
2.7	A 3 ³ full factorial design (27 points) (Bhattacharya, 2021)	24
2.8	Optimization target for first-order model vs. second-order model (Bhattacharya, 2021)	26
2.9	Types of urban farming	27
2.10	Different types of hydroponic systems (a) Deep Water Culture (b) Drip System (c) Aeroponics (d) Nutrient Film Technique (NFT) (e) 'Ebb and Flow' system (f) Aquaponics (Kyaw & Ng, 2017)	28
2.11	Aeroponics, hydroponics and aquaponics embedded in vertical farming (Helmentines, 2023)	31
2.12	Schematic diagram of macronutrient and micronutrient uptake in plants (Asha Kumari et al., 2022)	33
2.13	Comparison of lettuce plants after four weeks of plating in various types of treatment fertilizer; P ₀ : AB mix nutrients, P ₁ : NPK fertilizer 15:15:15, P ₂ : NPK fertilizer 12:14:12 (Utami Nugraha & Dinurrohman Susila, 2015)	37

2.14	3-D interaction graph between independent variables of the study and yield response of canola (Koocheki et al., 2014)	46
2.15	Interaction between PGPR and silicon doses with plant height (Kumar et al., 2020)	48
2.16	3-D contour and response surface plot of (a) bulb fresh weight and (b) plant dry weight (Kerckhoffs & Zhang, 2021)	49
2.17	3-D surface plots depicting the relationship between the height of the plant and two factors: wick length and the concentration of AB mix nutrients (Draman et al., 2021)	51
2.18	(a) ϵ_r' vs pH of soil-boric powder mixture (b) ϵ_r' vs pH of soil-NPK mixture (Mohan et al., 2015)	54
2.19	Graphs of (a) dielectric permittivity, ϵ' and (b) dielectric loss, ϵ'' vs. frequency, f for different moistening solutions of 0, 0.5, 1.0, and 1.5 S/m (Lewandowski et al., 2019)	55
2.20	$\sqrt{\epsilon'}$ vs. organic matter, (OM) content of various soil materials and water content at (a) 20 MHz and (b) 100 MHz (Szyplowska et al., 2021)	56
2.21	$\sqrt{\epsilon'}$ at 20 MHz vs. volumetric water content θ of all tested samples (Szyplowska et al., 2021)	57
2.22	Graph of S_{11} against frequency for sample 1 from Semenyih 2 plant (a) S_{11} real; (b) S_{11} imaginary (Zable et al., 2023)	59
2.23	Graph of S_{21} against frequency for sample 1 from Semenyih 2 plant (a) S_{21} real; (b) S_{21} imaginary (Zable et al., 2023)	59
3.1	Part A and part B were diluted with water in two (2) separate 100 L containers	63
3.2	Concentrated solutions of parts A and B diluted in 100 L containers	63
3.3	Mixing concentrated solution with water for dilution	64
3.4	HI98304 DiST® 4 Waterproof EC Tester for measuring the EC value of AB mix nutrients	64
3.5	Nutri-pot system	66
3.6	Nutri-pot covered with aluminium	66
3.7	Measuring the growth of <i>C. frutescens</i> tree using measuring tape	67

3.8	(a) Custom-made container with dimension 40 cm × 10 cm × 10 cm (b) AB mix nutrients were dripped into the containers for the first attempt of soil analysis	70
3.9	Smaller containers for soil samples with dimensions of 20 cm height and 70 mm diameter for XRF study	71
3.10	Soil samples in modified 450 mL bottles with 28 cm height and 70 mm diameter	73
3.11	Dripping process of AB mix nutrients into soil samples	73
3.12	Sample cells for XRF analysis	75
3.13	Soil sample in an acrylic sample holder for VNA analysis	75
3.14	Interface of Design Expert Ver. 13 software	77
3.15	Interface of CCD setup in Design Expert Ver. 13 software	77
3.16	Workflow of RSM in optimizing the AB mix nutrients towards <i>C. frutescens</i> plants	81-82
3.17	Energy Dispersive X-ray fluorescence, (EDXRF) at Physics Laboratory, Bangunan Jauhari UPNM	84
3.18	32 mm diameter sample chamber	85
3.19	Setup of Microwave Non-Destructive Testing (MNDT)	85
4.1	EDXRF profile of AB mix nutrients at different concentrations using RX-9 target from energy range 0 – 4 keV	95
4.2	EDXRF profile of AB mix nutrients at different concentration using Cu target from energy range 3 – 7.5 keV	97
4.3	EDXRF profile of AB mix nutrients at different concentration using Mo target from energy range 7 – 10 keV	98
4.4	EDXRF profile of controlled soil sample at different energy range using multiple targets of (a) RX-9 (b) Cu and (c) Mo	100
4.5	EDXRF profile of soil sample treated with 3 mL of AB mix nutrients at 1.4 mS/cm using multiple targets of (a) RX-9 (b) Cu and (c) Mo	102
4.6	EDXRF profile of soil sample treated with 6 mL of AB mix nutrients at 2.6 mS/cm using multiple targets (a) RX-9 (b) Cu (c) Mo	105-106

4.7	EDXRF profile of soil sample treated with 9 mL of AB mix nutrients at 3.5 mS/cm using multiple targets (a) RX-9 (b) Cu (c) Mo	107
4.8	Graph S_{11} against frequency, f for controlled soil sample of (a) graph for S_{11} real, (b) graph for S_{11} imaginary, (c) scattering plot for S_{11} real and (d) scattering plot for S_{11} imaginary	115
4.9	Graph of S_{21} against frequency, f for controlled soil sample of (a) graph for S_{21} real, (b) graph for S_{21} imaginary, (c) scattering plot for S_{21} real and (d) scattering plot for S_{21} imaginary	118
4.10	Graph S_{11} against frequency, f for top soil sample at 1.4 mS/cm with 3 mL AB mix nutrients application of (a) graph for S_{11} real, (b) graph for S_{11} imaginary, (c) scattering plot for S_{11} real and (d) scattering plot for S_{11} imaginary	120
4.11	Graph of S_{21} against frequency, f for top soil sample at 1.4 mS/cm with 3 mL AB mix nutrients application of (a) graph for S_{21} real, (b) graph for S_{21} imaginary, (c) scattering plot for S_{21} real and (d) scattering plot for S_{21} imaginary	122
4.12	Graph S_{11} against frequency, f for bottom soil sample at 3.5 mS/cm with 9 mL AB mix nutrients application of (a) graph for S_{11} real, (b) graph for S_{11} imaginary, (c) scattering plot for S_{11} real and (d) scattering plot for S_{11} imaginary	124
4.13	Graph S_{21} against frequency, f for bottom soil sample at 3.5 mS/cm with 9 mL AB mix nutrients application of (a) graph for S_{21} real, (b) graph for S_{21} imaginary, (c) scattering plot for S_{21} real and (d) scattering plot for S_{21} imaginary	126
4.14	Comparison graphs of dielectric constant, ϵ' vs soil samples at the top and bottom soil samples with different EC values and volumes of AB mix nutrients measured at 10 GHz	134
4.15	Illustration of polarization (Lee et al. 2003)	136
4.16	White fly found under several leaves of <i>C. frutescens</i> plant	142
4.17	Burnt and curling effects on the leaves observed in sample 11	143
4.18	Number of chillies produced increased significantly in Week 7	145
4.19	(a) – (m) The images for all plant samples at week 7 with their respective height, EC value and wick length used	146-147
4.20	Random sequence of runs	152

4.21	Diagnostic plots for developed model adequacy – predicted vs. actual	155
4.22	(a) Response Contour Plot and (b) 3D Surface Plot for interactive effects of EC value of AB mix nutrients and wick length on <i>C. frutescens</i> ' height	156
4.23	Diagnostic plots for developed model adequacy; (a) Residuals vs normal % probability; (b) Actual vs predicted; (c) Run number vs Cook's distance; (d) Run number vs residuals	158
4.24	Optimum condition of independent variables and the optimum response outcome computed by RSM	161

LIST OF ABBREVIATIONS

UPNM	-	University Pertahanan Nasional Malaysia
<i>C. Frutescens</i>	-	<i>Capsicum Frutescens</i>
ICP-OES	-	Inductively Coupled Plasma - Optical Emission Spectroscopy
EDXRF	-	Energy-Dispersive X-Ray Fluorescence
VNA	-	Vector Network Analysis
EC	-	Electrical Conductivity
RSM	-	Response Surface Methodology
ANOVA	-	Analysis of Variance
NPK	-	Nitrogen-Phosphorus-Potassium
DOA	-	Department Of Agriculture
WAP	-	Week After Planting
EM	-	Electromagnetic
DC	-	Direct Current
CCD	-	Central Composite Design
MNDT	-	Microwave Non-Destructive Technique
NFT	-	Nutrient Film Technique
ATP	-	Adenosine Triphosphate
LMO	-	Local Microorganisms
NUE	-	Nitrogen Use Efficiency
WUE	-	Water Use Efficiency
OM	-	Organic Matter
PVC	-	Polyvinyl Chloride
FRIM	-	Forest Research Institute Malaysia
RISDA	-	Rubber Industry Smallholders Development Authority
NRW	-	Nicholson-Ross-Weir

LIST OF SYMBOLS

ε'	- Dielectric constant
ε''	- Dielectric loss / imaginary part of permittivity
T	- Temperature
θ	- Angle of incidence / phase signal
λ	- Wavelength
f	- Frequency
C	- Carbon
P ₂ O ₅	- Phosphorus pentoxide
K ₂ O	- Potassium oxide
MgO	- Magnesium oxide
CaO	- Calcium oxide
Fe	- Iron
Co	- Cobalt
Ca	- Calcium
Ni	- Nickel
Pb	- Lead
B	- Boron
Mg	- Magnesium
Mn	- Manganese
Cu	- Copper
Zn	- Zinc
Cr	- Chromium
H ₄ SiO ₄	- Silicic acid
HCl	- Hydrochloric acid
HOCl	- Hypochlorous acid
SiO ₂	- Silicon dioxide

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Result on the content of AB mix nutrient using ICP-OES at RISDA Estate	182
B	Result of the soil test using ICP-OES at Soil Chemistry Lab, FRIM, Kepong towards controlled soil samples of different types	182
C-A	Pearson Correlation analysis between frequency, f and S-parameters of (i) S_{11} real and (ii) S_{11} imaginary controlled soil sample	183
C-B	Pearson Correlation analysis between frequency, f and S-parameters of (i) S_{21} real and (ii) S_{21} imaginary controlled soil sample	184
C-C	Pearson Correlation analysis between frequency, f and S-parameters of (i) S_{11} real and (ii) S_{11} imaginary top soil sample at 1.4 mS/cm with 3 mL AB mix nutrients application	185
C-D	Pearson Correlation analysis between frequency, f and S-parameters of (i) S_{21} real and (ii) S_{21} imaginary top soil sample at 1.4 mS/cm with 3 mL AB mix nutrients application	186
C-E	Pearson Correlation analysis between frequency, f and S-parameters of (i) S_{11} real and (ii) S_{11} imaginary bottom soil sample at 3.5 mS/cm with 9 mL AB mix nutrients application	187
C-F	Pearson Correlation analysis between frequency, f and S-parameters of (i) S_{21} real and (ii) S_{21} imaginary bottom soil sample at 3.5 mS/cm with 9 mL AB mix nutrients application	188
D	Growth condition of <i>C. frutescens</i> plant at different EC application from week 5 to week 7 (observation period)	189-193

CHAPTER 1

INTRODUCTION

1.1 Introduction to Fertilizers

Fertilizers are substances applied to soil or plants to provide essential nutrients that support plant growth and development. They supply nutrients that may be deficient in the soil, promoting healthier plants and increase crop yields. Fertilizers replenish the nutrients ensuring crops have access to the elements needed for optimal growth. Nutrient-rich soil leads to healthier plants with increased productivity (De Bon et al., 2010). Adequate nutrients result in larger, higher-quality harvests, contributing to farmers' food security and economic prosperity (Nadarajan & Sukumaran, 2021).

Fertilizers provide a balanced ratio of nutrients, promoting uniform growth across various plant parts. This balanced development enhances plant structure, making them better equipped to withstand environmental stressors such as drought, pests, and diseases (Rakshit et al., 2012). The three (3) primary nutrients contain in fertilizers are nitrogen, (N), phosphorus, (P) and potassium, (K) along with various micronutrients; nitrogen, (N) supports leaf and stem development, phosphorus, (P) encourages root growth and flowering and potassium, (K) enhances plant vigour and

disease resistance (Lin et al., 2019). These essential compounds provide plants with the nutrients they need for healthy growth, improved yield and overall agricultural sustainability (Hemathilake & Gunathilake, 2022). Another important feature of fertilizers is they offer a rapid and targeted response to nutrient deficiencies. This is particularly important when quick nutrient supplementation is needed to rectify deficiencies and prevent yield losses during critical growth stages. It has been reported that fertilizers can be tailored to specific crops and soil conditions, allowing farmers to meet the unique nutrient requirements of different plants (Silveira & Kohmann, 2020). Precision in nutrient application leads to efficient resource utilization and reduces the risk of nutrient wastage or environmental pollution.

There are two (2) types of fertilizers i.e. organic and inorganic. Organic fertilizers, which are derived from natural materials, such as plants and animal residues, provide nutrients to plants in less concentrated and more gradual manner compared to inorganic fertilizers. Unlike inorganic fertilizers, organic fertilizers need to undertake the decomposition process by soil microorganisms, which may take some time before their nutrients become available to plants (Pahalvi et al., 2021). Therefore, to increase the production of crops in a short time, inorganic fertilizers are often used.

Inorganic fertilizers, also known as synthetic or chemical fertilizers, are nutrient-rich compounds manufactured through industrial processes. Unlike organic fertilizers, the inorganics are chemically synthesized to contain specific ratios of nutrients that are vital for plant growth and development (Pahalvi et al., 2021). In addition to Nitrogen-Phosphorus-Potassium (NPK), inorganic fertilizers may also contain various micronutrients like iron, zinc, copper, manganese, molybdenum and