



**UNIVERSITI PUTRA MALAYSIA**

**SPATIAL VARIABILITY OF SOIL ELECTRICAL CONDUCTIVITY IN  
RELATION TO RICE YIELD FOR SITE-SPECIFIC FERTILIZER  
MANAGEMENT**

**ELTAIB SAEED MOHAMED GANAWA**

**FK 2003 35**



**SPATIAL VARIABILITY OF SOIL ELECTRICAL CONDUCTIVITY IN  
RELATION TO RICE YIELD FOR SITE-SPECIFIC FERTILIZER  
MANAGEMENT**

**By**

**ELTAIB SAEED MOHAMED GANAWA**

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

**May 2003**



*Dedicated to*

*'The estimable nucleolus in my life who championed my struggle'*

*My beloved Mother, Wife, Daughter and Family*



Abstract of thesis submitted to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

**SPATIAL VARIABILITY OF SOIL ELECTRICAL CONDUCTIVITY  
IN RELATION TO RICE YIELD FOR SITE-SPECIFIC FERTILIZER  
MANAGEMENT**

**By**

**ELTAIB SAEED MOHAMED GANAWA**

**May 2003**

**Chairman: Professor Ir Dr. Mohd Amin Mohd Soom**

**Faculty: Faculty of Engineering**

Describing the variability of nutrients status and electrical conductivity (EC) in the paddy soil is essential in developing a variable application rate of fertilizers. The main idea of precision agriculture understands spatial variability of soil properties, crop status and yield within a field; identifying the reasons for yield variability; making farming prescription and crop production management decisions based on variability and local knowledge. Field variability study was carried out in the Tanjung Karang rice irrigation scheme, northwest of Selangor, Malaysia. The general objective of this study was to obtain information about the distribution of soil electrical conductivity, soil nutrients in relation to rice yield to enable site-specific N, P and K fertilizers management in the paddy field. Collection of the soil samples was done at two depths (0-20 and 20-30 cm) using two different schemes from: (i) the small field (a typical 1.2 ha paddy plot), and (ii) a large irrigation compartment (2300 ha). Differential global positioning system (DGPS) was used to locate the sample



position. The soil samples were collected before seeding (BS), 15 days after seeding (15 DAS) and at tillering stage (TS). The rice yields were manually measured for two seasons at harvest. Variability of soil electrical conductivity (EC), soil nutrients and rice yield were determined using geostatistical method and classical statistics. Site-specific fertilizer recommendation maps of N, P and K were obtained using geographical information system (GIS) software. Accurate amount of N, P, and K fertilizer was investigated to replenish nutrient removal from the previous season. Descriptive statistical analysis showed variations between soils EC collected at different times. The spatial dependence level of the EC for all soil collection was moderate and the range was 118.39 m. The EC measurements can be used to estimate the soil nutrients and yield variations. High rice yield corresponds to high EC and soil nutrient values in the irrigation compartment. Yield is best related to EC and Nitrogen by the equation  $y=1.190+0.323EC+1.967N$  with  $r^2=0.732^{**}$ . In the small field, the spatial dependence of soil nutrients varied between moderate and weak for all soil collections. Based on the results of the study, the numbers of soil samples recommended to be taken from a small field (1.2 ha) are two for N, K and OM, and four for P and Mg. Soil sampling with the lowest N was observed at 15 DAS and high P was at TS, while high N, K and OM were found at BS. The amount of N fertilizer need to be added to the middle part of the small study area was 13.70 kg urea based on sampling at BS, but 64 kg urea at 15 DAS, and 24.5 kg urea at TS. Hence, soil sampling at BS could not indicate the actual amount of fertilizer need to be added. From the geostatistical analysis, the recommended yield sampling distance should be within 12.30 m. Thus, recommended fertilizer maps should be created



based on soil data and chlorophyll content collected during the rice growing stage. This will indicate the actual status of nutrients in soil. Site-specific fertilizer management offers a new method to reduce the cost of fertilizer application and preventing excessive chemical pollution to the environment.

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

**VARIASI SPATIAL KONDUKTIVITI ELEKTRIK TANAH, DALAM  
HUBUNGKAIT DENGAN HASIL PADI UNTUK PENGURUSAN BAJA  
MENGIKUT KEPERLUAN TAPAK**

**Oleh**

**ELTAIB SAEED MOHAMED GANAWA**

**Mei 2003**

**Pengerusi: Profesor Ir. Dr. Mohd Amin Mohd Soom**

**Fakulti : Fakulti Kejuruteraan**

Penerangan mengenai bahawa variasi status nutrien bagi tanah sawah padi dan konduktiviti elektrik adalah sangat penting dalam pembangunan aplikasi kadar variasi bagi baja. Pertanian Persis melibatkan pemahaman perubahan spatial ciritanah, status tanaman dan hasil padi dalam sawah, mengenalpasti sebab perbezaan hasil, memuat rawatan perladangan dan keputusan pengurusan pengeluaran tanamam berasakan perbezaan tersebut dan pengetahuan tempatan. Kajian ini dijalankan di Barat Laut Selangor, di kawasan Rancangan Pengairan Padi Tanjung Karang. Objektif umum bagi kajian ini adalah untuk mendapatkan maklumat semasa tentang pengagihan konduktiviti elektrik tanah, nutrien tanah dan hasil padi serta menentukan tapak spesifik pengurusan baja N, P dan K di kawasan padi. Pengumpulan sampel tanah telah dijalankan dalam kawasan berasingan (i) kawasan kecil (sebidang tanah sawah seluas 1.2 ha) dan (ii) sebuah kawasan pengairan seluas 2300 ha dengan dua



kedalaman (0-20 dan 20-30 cm). Sistem Kedudukan Global (DGPS) digunakan untuk menentukan kedudukan kawasan kajian tanah. Contoh tanah dikumpulkan pada tiga keadaan berbeza, iaitu sebelum penanaman, 15 hari selepas penanaman dan pada peringkat pembajakan. Hasil padi dikumpulkan secara manual pada dua musim. Parameter bagi penuaian, konduktiviti elektrik (EC), nutrien tanah dan hasil padi ditentukan. Analisis geostatistik dan statistik. Peta syor pembajaan tapak-mengikut keperluan tapak untuk N, P dan K diperolehi dengan menggunakan perisian sistem maklumat segajat (GIS). Jumlah kandungan yang baja N, P, dan K dikaji untuk menggantikan pengurangan nutrien yang berlaku pada musim yang lalu. Analisis gambaran statistik menunjukkan terdapat variasi diantara EC tanah yang dikumpulkan pada masa yang berbeza. Tahap EC bagi kesemua tanah yang dikumpul adalah sederhana dan berada di antara nilai 118.39m. Pengukuran EC dapat digunakan untuk menentukan nutrien tanah dan hasil variasi. Nilai EC dan nutrien tinggi tanah di kawasan pengairan yang berdekatan dengan laut. Di dalam kawasan yang kecil, nutrien tanah yang berubah di antara sederhana dan lemak pada semua tanah yang dikumpulkan. Hasil padi dapat dihubungkan dengan EC dan melalui persamaan  $y=1.190+0.323EC+1.967N$  dengan  $r^2=0.732^{**}$ . Bilangan sampel tanah dicadangkan untuk diambil daripada kawasan kecil pada perbezaan pengumpulan tanah berubah diantara dua dan empat sampel untuk pengasingan N, K dan OM dan P dan Mg. N terendah didapati pada 15 selepas sampel tanah diampil (15 DAP) dan P tinggi pada pengumpulan tanah peringkat pembajakan (TS), sedangkan N, K dan OM yang tinggi didapati pada pengumpulan tanah selepas menabur (BP) disebabkan oleh baki tumbuhan yang ditinggalkan oleh jentera penuai. Jumlah kandungan baja N yang



perlu ditambah kepada bahagian tengah kawasan kajian yang kecil adalah 13.70 kg urea berdasarkan kepada pengumpulan di BS, 64 kg urea di 15 DAS dan 24.5 kg urea di TS. Walaubagaimanapun pengumpulan tanah sebelum penanaman tidak memberikan status yang sebenar untuk jumlah baja yang perlu ditambah. Daripada analisis geostatistical jarak mengambil sampel yang disyorkan adalah ditanah 12.30 m. Oleh sebab itu peta pembajaan sepatutnya dibina berdasarkan ketika peringkat pertumbuhan padi. Ini akan menentukan status sebenar bagi nutrien didalam tanah. Pengurusan baja mengikut keperluan tapak menawarkan kaedah baru untuk mengurangkan kos baja dan pencemaran alam sekitar.

## ACKNOWLEDGEMENT

Alhamdulillah, first of all I would like to express my utmost thanks and gratitude to Almighty Allah S.W.T who has given me the capability to complete this thesis research project and my salawat to His righteous messenger, prophet Mohammed s.a.w.

I would like to take this opportunity to express my appreciation and gratitude to the chairman of my supervisory committee, Professor Ir Dr Mohd Amin Mohd Soom for his valuable suggestion, superb guidance, discussion and patience throughout the project duration. I am also very grateful to the members of my supervisory committee Assoc Prof Dr Mohd Hanafi Musa and Dr Abdul Rashid Mohamed Shariff for their constructive comments towards the preparation of this thesis and counseling which has enabled me to accomplish the objectives of this research in a professional and scholarly manner.

I am indebted to all staff of the Department of Biological and Agricultural Engineering, Faculty of Engineering; and Land Management Department Faculty of Agriculture for their generous cooperation. Acknowledgment is also due to all laboratory assistants Ghazali Kassim, Abdul Rahim bin Utar, Jamil bin Omar and Puan Fauziah Suliman. I would like to convey my appreciation to Malaysian Centre for Remote Sensing (MACRES) for their assistance during the field work. Special thanks to my friend Aimrun Wayayok for his assistance during my field work in



Sawah Sempadan. I would like to extend to my friends in Malaysia who has contributed their support directly or indirectly to this study.

My sincere gratitude to my wife Fatima Awad Allah and my brother Mohamed Saeed who showed deep insight on the mundane nature of my work and chubs for their never-ending forbearance eased my endeavor through this challenging passage of life. I am also very grateful to my father in law Dr Awad Allah Mohamed, my mother and sister in law Haja Batol and Faiga for their support and encouragement.

Finally and most important, I would like to express my most sincere and warmest gratitude to my beloved mother Haja Haninah Khalaf Allah, brothers, uncle, aunts and nephews, and nieces for their prayers, love, generous moral support during my study. Not forgotten my friends in my beloved village Eltalbab: Atif Elhadi, Asim Abdullah, Khalid Khalifa, Rashid Eljalli, Galal Eljalli and Mamoun Ahmed and to my friends in Shamabt Abdallah Madani, Eltahir Ibrahim, Nour Elgalil, Mohamed Elawad, Tarig Hassan, Munier Elyass and Osama Omer for their correspondence and concern during the period of my stay in Malaysia.



## TABLE OF CONTENTS

	Page
DEDICATION	iii
ABSTRACT	iv
ABSTRAK	vi
ACKNOWLEDGMENTS	ix
APPROVAL SHEETS	xi
DECLARATION FORM	xiii
TABLE OF CONTENTS	xiv
LIST OF TABLES	xviii
LIST OF FIGURES	xx
LIST OF ABBREVIATIONS	xxiii
 <b>CHAPTER</b>	
<b>1 INTRODUCTION</b> .....	<b>1.1</b>
1.1 General Introduction.....	1.1
1.2 Problem Statement.....	1.4
1.3 Objectives of the Study.....	1.5
1.4 Scope of the Study.....	1.6
1.5 Organization of the Thesis .....	1.7
 <b>2 LITERATURE REVIEW</b> .....	 <b>2.1</b>
2.1 Precision Farming Applications.....	2.1
2.1.1 Technology Elements.....	2.3
2.1.1.1 Describing a Variability.....	2.3
2.1.1.2 Variable-rate Control.....	2.4
2.1.1.3 Decision Support System for Managing Variability.....	2.4
2.2 Variability and Crop Production.....	2.5
2.2.1 Soil Factor.....	2.5
2.2.2 Topography.....	2.6
2.2.3 Climate.....	2.7
2.2.4 Pest Management.....	2.7
2.2.5 Yield.....	2.7
2.3 Soil Specific Crop Management.....	2.8
2.3.1 Soil Variability Affected by Nature and Man.....	2.9
2.3.2 Assessing the Variability.....	2.10
2.3.3 Soil Management Zones.....	2.10
2.3.4 Engineering Technology for Soil Specific Crop Management.....	2.11
2.3.4.1 Data Acquisition.....	2.11
2.3.4.2 Engineered System.....	2.12
2.4 Geostatistics Analysis.....	2.12
2.4.1 Estimation of the Variogram.....	2.13
2.4.2 Linear Isotropic Model.....	2.17
2.4.3 Exponential Isotropic Model.....	2.18



2.4.4	Spherical Model.....	2.19
2.4.5	Kriging Analysis.....	2.21
2.5	Global Positioning Application in Precision Farming.....	2.24
2.5.1	Global Positioning System Navigation.....	2.25
2.5.2	The GPS System .....	2.26
2.5.3	Differential Global Positioning System.....	2.27
2.5.4	Mapping from GPS Data.....	2.28
2.6	Geographic Information System.....	2.29
2.6.1	Spatial Model Overlay Function in GIS.....	2.30
2.5.3	Geographical Information System (GIS) for Precision Farming....	2.31
2.7	Methods of Soil Samples Collection.....	2.34
2.7.1	Traditional Composite Sampling.....	2.34
2.7.2	The Grid Sampling.....	2.35
2.7.3	Landscape Directed Soil Sampling.....	2.36
2.8	Rice Granary Background.....	2.37
2.8.1	Soil Chemical Properties and Rice Production.....	2.39
2.9	Electrical Conductivity Mapping.....	2.41
2.9.1	Uses of Electrical Conductivity Maps.....	2.43
2.9.2	Interpretation of Electrical Conductivity.....	2.43
2.10	Past and Current Research on Site-specific Management in Malaysia.....	2.47
<b>3</b>	<b>MATERIALS AND METHODS.....</b>	<b>3.1</b>
3.1	Location and Topographic of the Study Area.....	3.1
3.1.1	Climate.....	3.3
3.1.2	Soil Characteristics.....	3.3
3.2	Sampling Design and Soil Collection.....	3.5
3.2.1	The Small Field .....	3.5
3.2.1.1	Plot Characteristics and Soil Collection.....	3.6
3.2.2	Characteristics of Irrigation Compartment and Soil Collection.....	3.8
3.2.3	Locating Soil Samples by Differential Global Positioning System.....	3.10
3.2.3.1	Differential Global Positioning System Instrument....	3.10
3.2.3.2	Differential Global Positioning System Setting, Base Station Data and Data Recording.....	3.11
3.3	Samples Preparation and Analysis.....	3.13
3.3.1	Soil Samples Preparation.....	3.13
3.3.1.1	Dry samples.....	3.13
3.3.1.2	Wet samples .....	3.13
3.3.2	Soil Samples Analysis .....	3.14
3.3.2.1	Total N, Available P and Exchangeable K, Mg and CEC.....	3.14
3.3.2.2	Organic Matter .....	3.14
3.3.2.3	Soil pH.....	3.15
3.3.2.4	Soil Electrical Conductivity.....	3.15



	3.3.2.5 Soil Particle Size Distribution.....	3.15
	3.3.2.6 Bulk Density.....	3.16
	3.3.2.7 Soil Water Content .....	3.16
3.4	Harvesting of Rice.....	3.16
3.5	Statistical Analysis.....	3.17
	3.5.1 Descriptive Statistics.....	3.17
	3.5.2 Geostatistical Analysis.....	3.19
3.6	Site-specific Fertilizer Management.....	3.21
	3.6.1 Economic Rate of Fertilizers in the Small Field.....	3.21
	3.6.2 Model Validation.....	3.22
<b>4</b>	<b>RESULTS AND DISCUSSION.....</b>	<b>4.1</b>
4.1	Variation of Electrical Conductivity in Small Field.....	4.1
	4.1.1 Soil Collection before Seeding, 15 Days after Seeding and at Tillering Stage.....	4.1
4.2	Spatial Distribution of Electrical Conductivity in Small Field.....	4.7
	4.2.1 Semivariance Analysis of EC for Small field.....	4.7
	4.2.2 Spatial Distribution Maps of Electrical Conductivity in a Small Field .....	4.9
	4.2.2.1 Kriged Maps of Soil collection Before Seeding.....	4.9
	4.2.2.2 Kriged Maps of Wet Soil during Rice Growing at 15 Days after Seeding.....	4.12
	4.2.2.3 Kriged Maps of Wet Soil at Tillering Stage.....	4.14
4.3	Variation of Electrical Conductivity in Irrigation Compartment Field ....	4.17
	4.3.1 Variations of Soil Collection before Seeding, 15 Days after Seeding and at Tillering stage.....	4.17
4.4	Spatial Distribution Maps of Electrical Conductivity in an Irrigation Compartment Field .....	4.22
	4.4.1 Kriged Maps of Soil Collected before Seeding.....	4.22
	4.4.2 Kriged Maps of Wet Soil Collected 15 Days after Seeding.....	4.25
	4.4.3 Kriged Maps of Wet Soil Collected at Tillering Stage.....	4.27
4.5	Variation of Soil Properties in Small Field.....	4.29
	4.5.1 Variations of Soil Collection before Seeding, 15 Days after Seeding and at Tillering Stage.....	4.29
4.6	Semivariance Analysis of the Small Field .....	4.39
	4.6.1 Semivariance of Soil Collection before Seeding, during rice growing 15 DAS and at Tillering stage.....	4.39
4.7	Spatial Distribution Maps of Soil Properties in Small field.....	4.49
	4.7.1 Kriged Maps of Soil Collection before Seeding .....	4.49
	4.7.1.1 Model validation.....	4.58
	4.7.2 Kriged Maps of Soil Collection at 15 Days after Seeding .....	4.59



4.7.3	Kriged Maps of Soil Collection at Tillering Stage.....	4.70
4.8	Variation of Soil Properties in Irrigation Compartment Field.....	4.79
4.8.1	Variations of Soil Collection before Seeding , 15 Days after Seeding and at Tillering Stage.....	4.79
4.9	Spatial Distribution Maps of Soil Properties in Irrigation Compartment .....	4.89
4.9.1	Kriged Maps of Soil Collection before Seeding .....	4.89
4.9.2	Kriged Maps of Soil Collection at 15 Days after Seeding .....	4.97
4.9.3	Kriged Maps of Soil Collection at Tillering Stage.....	4.106
4.10	Statistical Analysis of Rice Yield in a small Field.....	4.114
4.11	Linear Regression of Rice Yield in a Small Field.....	4.115
4.12	Spatial Distribution Analysis of Rice Yield in a Small Field.....	4.120
4.12.1	Semivariance Analysis of Rice Yield.....	4.120
4.12.2	Spatial Distribution Maps of Rice Yield in a Small field.....	4.122
4.12.2.1	Kriged Maps of Rice Yield in First Season.....	4.122
4.12.2.2	Kriged Maps of rice Yield in Second Season.....	4.125
4.13	Statistical Analysis of Rice Yield in the Irrigation Compartment.....	4.127
4.14	Rice Yield Linear Regression Model in Irrigation Compartment.....	4.129
4.15	Spatial Distribution Maps of Rice Yield in Irrigation Compartment....	4.133
4.15.1	Kriged Maps of Rice Yield in First Season.....	4.133
4.15.2	Kriged Maps of Rice Yield in Second Season.....	4.134
4.16	Fertilizer Management in a Small Field.....	4.136
4.16.1	Nitrogen Fertilizer Management.....	4.136
4.16.2	Phosphorus Fertilizer Management.....	4.140
4.16.3	Potassium Fertilizer Management.....	4.143
4.16.4	The Benefits of Using Site Specific Fertilizer Management.....	4.147
5	<b>CONCLUSIONS AND RECOMMENDATIONS.....</b>	5.1
	<b>REFERENCES.....</b>	R.1
	<b>APPENDICES.....</b>	A.1
	Appendix A.....	A.1
	Appendix B.....	A.11
	Appendix C.....	A.15
	<b>VITA.....</b>	V.1



## LIST OF TABLES

Table	Page
2.1 Potential Uses of EC Maps.....	2.44
3.1 Soil Classification of Soil Series in Study Area.....	3.5
4.1 Descriptive Statistics of EC for dry soil Collected after Harvesting.....	4.2
4.2 Descriptive Statistics of EC for Wet Soil at 15 Days after Seeding.....	4.2
4.3 Descriptive Statistics of EC for Wet Soil at Tillering Stage.....	4.2
4.4 Correlation between EC with Soil Properties and Yield in Small Field.	
4.5 Descriptive Statistics of CEC and pH for Dry Soil.....	4.7
4.6 Semivariogram of EC for Soil Collection at AH, 15 DAS and TS for Small Field.....	4.8
4.7 Descriptive Statistics of EC for Dry soil Collected before Planting.....	4.17
4.8 Descriptive Statistics of EC for Wet Soil at 15 DAS.....	4.18
4.9 Descriptive Statistics of EC for Wet Soil at Tillering Stage.....	4.19
4.10 Correlation between EC with Soil Properties and Yield Irrigation Compartment.....	4.20
4.11 Descriptive Statistics of CEC and pH of Soil Collection before Planting.....	4.21
4.12 Descriptive Statistics of Soil Properties for Dry Soil of Small Field.....	4.30
4.13 Descriptive Statistics of Soil Properties for 15 DAS of Small Field.....	4.32
4.14 Descriptive Statistics of Soil Properties for TS of Small Field.....	4.33
4.15 T-test Comparison between top- and sub-soil layer at Different Soil Collections.....	4.34
4.16 Correlation Analysis of Some Soil Properties for the Top-soil Layer for Soil Collected before Seeding.....	4.36
4.17 Correlation Analysis of Some Soil Properties for the Sub-soil Layer for Soil Collected before Seeding.....	4.36
4.18 Correlation Analysis of Some Soil Properties for the Top-soil Layer for Soil Collected 15 DAS.....	4.37
4.19 Correlation Analysis of Some Soil Properties for the Sub-soil Layer for Soil Collected 15 DAS.....	4.37
4.20 Correlation Analysis of Some Soil Properties for the Top-soil Layer for Soil Collected at TS.....	4.38
4.21 Correlation Analysis of Some Soil Properties for the Top-soil Layer for Soil Collected at TS.....	4.39
4.22 Semivariogram of Soil Collected before Seeding.....	4.43
4.23 Semivariogram of Soil Collected at 15 DAS.....	4.44
4.24a Semivariogram of Soil Collected at Tillering Stage.....	4.47
4.24b Selected Points for Model Validation.....	4.58
4.25 Descriptive Statistics of Soil Properties for Soil Collected before Planting In the Irrigation Compartment.....	4.80
4.26 Descriptive Statistics of Soil Properties for Soil Collected at 15 DAS in the Irrigation Compartment.....	4.81





4.27a	Descriptive Statistics of Soil Properties for Soil Collected at Tillering Stage in the Irrigation Compartment.....	4.82
4.27b	T-test Comparison between top- and sub-soil layer for all different Soil Collections.....	4.84
4.28	Correlation Analysis of Some Soil Properties for the Top-soil Layer for Soil Collected before Seeding .....	4.85
4.29	Correlation Analysis of Some Soil Properties for the Sub-soil Layer for Soil Collected before Seeding .....	4.85
4.30	Correlation Analysis of Some Soil Properties for the Top-soil Layer for Soil Collected at 15 DAS.....	4.86
4.31	Correlation Analysis of Some Soil Properties for the Sub-soil Layer for Soil Collected at 15 DAS.....	4.87
4.32	Correlation Analysis of Some Soil Properties for the Top-soil Layer for Soil Collected at Tillering Stage.....	4.88
4.33	Correlation Analysis of Some Soil Properties for the Sub-soil Layer for Soil Collected at Tillering Stage.....	4.88
4.34	Descriptive Statistics of a Rice Yield for First and Second Season.....	4.115
4.35	Correlation Analysis between Rice Yield and Soil Nutrients for Small Field.....	4.115
4.36	The Linear Model Summary.....	4.116
4.37	The Analysis of Variance of the Regression Model.....	4.117
4.38	Coefficients for the Regression Model.....	4.119
4.39	Semivariogram Features for Small Field.....	4.121
4.40	Descriptive Statistics of a Rice Yield for First and Second Season.....	4.128
4.41	Correlation Analysis between Rice Yield and Soil Nutrients for Irrigation Compartment.....	4.128
4.42	The Linear Model Summary.....	4.130
4.43	Analysis of Variance of the Regression Model.....	4.130
4.44	Coefficients for the Regression Model.....	4.131
4.45	The Calculation of the Economic Benefits of Using SSFM.....	4.147



## LIST OF FIGURES

<b>Figure</b>		<b>Page</b>
2.1	Elements of Precision Farming .....	2.2
2.2	Diagram of the Variogram.....	2.16
2.3	Calculation of the Variogram.....	2.17
2.4	Linear model.....	2.18
2.5	Exponential Model.....	2.19
2.6	Spherical Model.....	2.20
2.7	Comparison between Deterministic and Stochastic Interpolation.....	2.23
2.8	Map of C Microbial (Sabit, 2001).....	2.23
2.9	Kriging Map of Estimated Phosphorus (Clay, 1999).....	2.24
2.10	Use of Hand held DGPS (Taib, 2001).....	2.27
2.11	GPS application in Precision farming. Source (Auernhammer, 2001).....	2.29
2.12	Soil Sampling a) Traditional Composite b) Grid Systematic and c) Landscape direct.....	2.36
2.13	Land Preparation and Harvesting for Rice.....	2.38
2.14	Soil Electrical Conductivity Generated Map for Site-specific Applications. ....	2.36
2.15	Correlation between EC, OM and Clay .....	2.42
2.16	Correlation between EC and N .....	2.47
3.1	A map of Malaysia showing the Study Area.....	3.2
3.2	The Soil Series of the Study Area.....	3.4
3.3	Grid Sampling of Small Field.....	3.7
3.4	Plots of Soil Sampling Sites Located Using DGPS.....	3.10
3.5	Full Package of DGPS Used in The Study.....	3.11
3.6	The DGPS Recording of Soil Sampling Location .....	3.12
3.7	Flowchart Procedure of Developing a Fertilizer Map.....	3.23
3.8	Calculation of Economic rate of N, P, and K Fertilizer .....	3.24
4.1	The Distribution of Soil Texture for (a) top- and (b) sub-soil layer in the Small Field.....	4.4
4.2	Semivariogram of EC, (a) dry collection (b) 15 DAS, and (c) TS.....	4.9
4.3	Variability Map of EC (a) top- and (b) sub-soil layer of 1.2 ha Paddy Plot of Dry soil Collected before Seeding .....	4.11
4.4	Variability Map of EC (a) top- and (b) sub-soil layer of 1.2 ha Paddy Plot of Wet Soil Collected at 15 Days after Seeding .....	4.13
4.5	Variability Map of EC (a) top- and (b) sub-soil layer of 1.2 ha Paddy Plot of Wet soil Collected at Tillering Stage.....	4.16
4.6	The Distribution of Soil Texture for a) top- and b) sub-soil.....	4.22
4.7	Variability Map of EC (a) top- and (b) sub-soil layer for an Irrigation Compartment for Dry Soil Collected after Harvesting.....	4.24
4.8	Variability Map of EC (a) top- and (b) sub-soil layer for an Irrigation Compartment for Wet Soil Collected at 15 Days after Seeding .....	4.26
4.9	Variability Map of EC (a) top- and (b) sub-soil layer for an Irrigation Compartment for Dry Soil Collected at Tillering Stage.....	4.28
4.10	Semivariogram for (a) N, (b) P, (c) K, (d) Mg, and (e) OM for Small Field.....	4.42



4.11	Semivariogram for (a) N, (b) P, (c) K, (d) Mg, and (e) OM of a Small Field.....	4.45
4.12	Semivariogram for (a) N, (b) P, (c) K, (d) Mg, and (e) OM of Small Field	4.48
4.13	Variability map of total N for (a) top- and (b) sub-soil layer of Soil Collected before Seeding .....	4.50
4.14	Variability map of available P for top- and (b) sub-soil layer of Soil Collected before Seeding .....	4.51
4.15	Variability map of exchangeable K of (a) top- and (b) sub-soil layer of Soil Collected before Seeding .....	4.54
4.16	Variability map of exchangeable Mg of (a) top- and (b) sub-soil layer of Soil Collected before Seeding .....	4.55
4.17a	Variability map of total OM of (a) top- and (b) sub-soil layer of Soil Collected before Seeding .....	4.57
4.17b	Low Yield and Soil properties in Middle Part.....	4.58
4.18	Variability map of Total N of (a) top- and (b) sub-soil layer of Soil Collected at 15 DAS.....	4.60
4.19	Variability Map of Available P of (a) top- and (b) sub-soil layer of Soil Collected at 15 DAS.....	4.64
4.20	Variability Map of Exchangeable K of (a) top- and (b) sub-soil layer of Soil Collected at 15 DAS.....	4.65
4.21	Variability Map of Exchangeable Mg of (a) top- and (b) sub-soil layer of Soil Collected at 15 DAS.....	4.67
4.22	Variability Map of Total OM of (a) top- and (b) sub-soil layer of Soil Collected at 15 DAS.....	4.69
4.23	Variability Map of Total N of (a) top- and (b) sub-soil layer of Soil Collected at Tillering Stage.....	4.71
4.24	Variability Map of Available P of (a) top- and (b) sub- soil layer of Soil Collected at Tillering Stage.....	4.73
4.25	Variability Map of Exchangeable K for (a) top- and (b) sub-soil layer of Soil Collected at Tillering Stage.....	4.74
4.26	Variability Map of Exchangeable Mg for (a) top- and (b) sub-soil layer of Soil Collected at Tillering Stage.....	4.77
4.27	Variability Map of Total OM of (a) top- and (b) sub-soil layer of Soil Collected at Tillering Stage.....	4.78
4.28	Variability map of total N of (a) top- and (b) sub-soil layer for Soil Collected before Seeding .....	4.90
4.29	Variability map of available P (a) top- and (b) sub-soil layer for Soil Collected before Seeding .....	4.92
4.30	Variability map of exchangeable K for (a) top- and (b) sub-soil layer for Soil Collected before Seeding .....	4.93
4.31	Variability map of Exchangeable Mg for (a) top- and (b) sub-soil layer for Soil Collected before Seeding .....	4.95
4.32	Variability map of total OM for (a) top- and (b) sub-soil layer for Soil Collected before Seeding .....	4.96
4.33	Variability map of Total N (a) top- and (b) sub-soil layer For Soil Collected at 15 DAS.....	4.99



4.34	Variability map of Available P (a) top- and (b) sub-soil For Soil Collected at 15 DAS.....	4.100
4.35	Variability map of exchangeable K for (a) top- and (b) sub-soil layer For Soil Collected at 15 DAS.....	4.102
4.36	Variability map of Exchangeable Mg for (a) top- and (b) subsoil layer For Soil Collected at 15 DAS.....	4.104
4.37	Variability map of total OM for (a) top- and (b) sub-soil layer For Soil Collected at 15 DAS.....	4.105
4.38	Variability map of Total N top- and (b) sub-soil layer For Soil Collected at Tillering Stage.....	4.107
4.39	Variability map of Available P top- and (b) sub-soil layer For Soil Collected at Tillering Stage.....	4.109
4.40	Variability map of Exchangeable K for (a) top- and (b) sub-soil layer For Soil Collected at Tillering Stage.....	4.110
4.41	Variability map of Exchangeable Mg for (a) top- and (b) sub-soil layer For Soil Collected at Tillering Stage.....	4.112
4.42	Variability map of total OM for (a) top- and (b) sub-soil layer For Soil Collected at Tillering Stage.....	4.113
4.43	Semivariogram of Rice Yield for (a) First and (b) Second Season.....	4.122
4.44	Spatial Distribution of Rice Yields in a Small Field (First Season).....	4.123
4.45	Spatial Distribution of Rice Yields in a Small Field (Second Season).....	4.126
4.46	Spatial Distribution of Rice Yields in Irrigation Compartment (FS)....	4.134
4.47	Spatial Distribution of Rice Yields in Irrigation Compartment (SS).....	4.135
4.48	Amount of Urea to be added based on Soil Nutrients Status before Seeding .....	4.137
4.49	Amount of Urea to be added based on Soil Collected at 15 days after Seeding .....	4.138
4.50	Amount of Urea to be added based on Soil Collected during Rice Growing at Tillering Stage.....	4.139
4.51	The Amount of Required and Actual P based on Soil Collected before Seeding .....	4.140
4.52	The Amount of Required and Actual P based on Soil Collected at 15 DAS.....	4.141
4.53	The Amount of Required and Actual P based on Soil Collected at Tillering Stage.....	4.142
4.54	The Amount of Required and Actual K based on Soil collected before Seeding .....	4.143
4.55	The Amount of Required and Actual K based on Soil Collected during Rice Growing at 15 DAS.....	4.144
4.56	The Amount of Required and Actual K based on Soil Collected at Tillering Stage.....	4.145



## LIST OF ABBREVIATIONS

PF	Precision Farming
EC	Electrical Conductivity
GIS	Geographical Information System
GPS	Global Positioning System
IPM	Integrated Pest Management
SSCM	Soil Specific Crop Management
IDW	Inverse Distance Weight
GNSS	Global Navigation Satellite Systems
VRT	Variable Rate Technology
DGPS	Differential Global Positioning System
DOA	Department of Agriculture
CIRP	Christmas Island Rock Phosphate
MOP	Muriate of Potash
mS/m	milliSiemens per meter
CEC	Cation Exchange Capacity
dS/m	decisiemens per meter
mg kg <sup>-1</sup>	milligram per kilogram
kg	kilogram
MARDI	Malaysian Agriculture and Development Institute
m	meter
ha	hectare
cm	centimeter
BS	Before Seeding
15 DAS	15 Days after Seeding
TS	Tillering Stage
OC	Organic Carbon
OM	Organic Matter
N	Nitrogen
P	Phosphorus
K	Potassium
Mg	Magnesium
AA	Auto Analyzer
AAS	Atomic Absorption Spectrophotometer
$\gamma(h)$	semi-variance
$h$	lag
$n$	number of observation
$X(i)$	value of the current point
$X(i = h)$	value of the point at lag $h$
$C+C_0$	Sill
$C_0$	Nugget
$a$	Range



# CHAPTER I

## INTRODUCTION

### 1.1 General Introduction

Precision farming (PF) is a new concept for sustainable utilization of agricultural resources defined as the management of arable variability to improve the economic benefit and reduce environmental impact (Blackmore, 2001). Precision farming sometimes called site-specific farming or variable rate technology. This definition serves a two-fold purpose. Firstly, it identifies management of variability as the essential factor and not a technology as many people seem to believe. Secondly, it identifies the drivers for changing the existing systems, improving the economic returns while reducing the impact of management practices on the environment. Both of these drivers work in the same way to improve the efficiency of the agricultural process. The manner in which these drivers are implemented will vary depending on different crops and countries concerned. Underlying these different implementations are the principles that applied universally.

The main ideas of precision agriculture are understanding spatial variability of soil properties, crop status and yield within a field; identifying the reasons for yield variability; making farming prescription and crop production management decisions based on variability and knowledge; implementing site-specific field management

