SPATIAL APPARENT ELECTRICAL CONDUCTIVITY OF PADDY SOIL AS AN INDICATOR OF RICE PRODUCTIVITY

By

CHAN CHEE SHENG

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

May 2006

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

SPATIAL APPARENT ELECTRICAL CONDUCTIVITY OF PADDY SOIL AS AN INDICATOR OF RICE PRODUCTIVITY

By

CHAN CHEE SHENG

May 2006

Chairman: Professor Ir. Mohd Amin Mohd Soom, PhD

Faculty : Engineering

Paddy soils are naturally heterogeneous in terms of their physico-chemical properties which influence rice productivity. Currently, uniform application of agricultural fertilizers for the entire field is not efficient and could result in either insufficient or excess nutrient supply. Good agricultural practices can be achieved if soil and nutrient variations within a farm are considered, and a soil-yield interrelationship is established. Simple, rapid and accurate methods to characterize variation in soil properties are needed.

This study was conducted on two different plots within Malaysia Agricultural Development and Research Institute (MARDI) Research Station located at the northern part of Peninsular Malaysia. One of the plots is a single large contiguous plot of 9-ha, free of farm encumbrances and the other is equipped with subsurface drainage facilities. Soil samples were collected at regular grid spacing from the upper (0-20 cm) and lower (30-50 cm) soil layers respectively. These samples were analyzed for their soil texture and chemical properties. Crop cutting test yields

were taken at the same soil sampling locations. Geo-referenced apparent electrical conductivity (ECa) measurements were obtained by using Veris 3100 cart equipped with a data logger and a differential global positioning system.

Soil ECa mapping is a simple and rapid tool that can be used to provide estimate of the within field soil differences associated with soil properties which is a measure of field conditions and soil suitability for crop growth and yield. The significant correlations of soil ECa and mapping date showed that the patterns of soil ECa within a field do not tend to change significantly over time. Generally, once an ECa map has been made, it will remain relatively accurate unless significant soil movements occur. The correlations between shallow and deep soil ECa were found to be significant too. And significant relationships between potential grain yield and ECa were found using a form of boundary line analysis in scatter plots with $r^2 >$ 0.58 in all the six investigations in three crop-seasons. The log-normal function chosen to fit the boundary datasets was flexible in representing various responses combination to ECa values and could correctly indicated significant higher yield can be obtained from areas with high predicted potential yield. Comparison of Ypo and Yob can delineate farm areas into different management zones and allows for discriminate management practices particularly to low yield areas due to less then ideal field conditions, thus resulting good agricultural practices. These practices could result in less wastage of applied inputs, less pollution, lower input costs and most important higher return.

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

SPATIAL KONDUKTIVITI ELEKTRIK BERKELIHATAN TANAH SAWAH SEBAGAI PENUNJUK PENGHASILAN PADI

Oleh

CHAN CHEE SHENG

Mei 2006

Pengerusi: Profesor Ir. Mohd Amin Mohd Soom, PhD

Fakulti : Kejuruteraan

Ciri-ciri fizikal dan kimia tanah sawah adalah berbeza-beza dalam keadaan semula jadi dan mempengaruhi daya pengeluaran padi. Pada masa ini, pembajaan yang seragam untuk seluruh tanah sawah adalah tidak cekap dan menyebabkan pembekalan nutrisi yang kurang atau berlebihan. Kaedah pengurusan penanaman yang baik dapat dicapai jika perbezaan nutrisi di sesuatu ladang dapat dipertimbangkan, dan hubungan di antara tanah dan hasil dapat diwujudkan. Maka, cara yang mudah, cepat dan tepat untuk menggambarkan perbezaan ciri-ciri tanah diperlukan.

Kajian ini dilaksanakan pada dua petak dalam Stesen Penyelidikan Institut Penyelidikan dan Kemajuan Pertanian Malaysia (MARDI) yang berletak di utara Semenanjung Malaysia. Salah satu petak adalah petak seluas 9-ha sekeping tanpa beban ladang dan satu petak yang lagi dilengkapi dengan kemudahan sistem saliran di bawah permukaan tanah. Sampel tanah dikumpul pada jarak grid yang

sama dari lapisan tanah atas (0-20 cm) dan lapisan bawah (30-50 cm). Ciri-ciri tekstur dan kimia tanah telah dianalisa dari sampel tersebut. Hasil padi ditentukan dengan cara 'crop cutting test' pada kawasan yang sama dengan kawasan sampel tanah. Ukuran konductiviti elektrik berkelihatan (ECa) yang dirujukkan bersama kedudukannya dengan kemudahan geografi diambil dengan menggunakan alat Veris 3100 yang dilengkap dengan data logger dan DGPS.

Pemetaan ECa tanah adalah alat yang mudah dan pantas untuk memberikan anggaran perbezaan tanah di sesuatu tapak ladang yang bersangkut dengan cirri-ciri tanah. Ianya boleh digunakan untuk menyukat kesesuaian tanah untuk pertumbuhan tanaman dan hasilnya. Korelasi yang bermakna di antara ECa tanah dan tarikh ukuran menunjukkan corak ECa tanah di sesebuah ladang tidak banyak berubah dari masa ke semasa. Pada umumnya, apabila peta ECa tanah telah di buat, ia akan kekal tepat kecuali tanah diusik dengan banyak. Korelasi yang nyata di antara ECa tanah cetek dan dalam juga ditemui. Perhubungan yang nyata di antara hasil potensi (Ypo) dan ECa ditemui dengan $r^2 > 0.58$ dengan cara analisa garisan sempadan daripada keenam-enam kajian dalam tempoh tiga tahun. Fungsi log-normal dipilih untuk memadan set data sempadan adalah flesibel untuk mudah mewakili reaksi nilai ECa, dan juga dapat menunjukkan dengan tepat hasil yang tinggi boleh diperolehi dari kawasan yang berpotensi hasil tinggi.
Perbandingan di antara Ypo dan hasil permerhatian (Yob) dapat membahagikan kawasan ladang kepada zon pengurusan yang berbeza, membolehkan pembajaan yang berlainan terutamanya di kawasan yang berhasil rendah kerana keadaan ladang yang tidak sempurna. Maka, ini dapat menghasilkan amalan pertanian

yang baik. Amalan ini dapat mengurangkan pembaziran nutrisi, kurang pencermaran, rendah perbelanjaan dan paling penting memberi pulangan yang tinggi.

ACKNOWLEDGEMENTS

The author is greatly indebted to his Supervisor, Professor Ir. Dr Mohd Amin Mohd Soom, Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia for the scholastic advice and worthy inspiration for his research works.

Thanks are also due to his Supervisory Committee members Associate Professor Ir. Dr Lee Teang Shui from Faculty of Engineering and Dr Mohammud Che Husain from Malaysian Agricultural Research and Development Institute (MARDI), Serdang for their advice, constructive criticism and comments for the study.

The author also would like to express his profound appreciation to MARDI and the Intensification of Research in Priority Areas (IRPA) programme, Ministry of Science, Technology, and Environment Malaysia for providing financial support during the study.

Appreciations also go to the Bio-Engineering Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia for lending the Veris 3100 equipment

through Prof. Ir Dr Mohd Amin Mohd Soom for this current study. The author would like to express his most sincere and warmest gratitude to the staff of MARDI, Seberang Perai who has contributed their support directly or indirectly to this study.

Last but not least, the author would like to take this opportunity to express his appreciation and gratitude to his wife Beh Tuan Imm, his children Chan Hai Feng, Chan Haw Feng and Chan Yit Yih and his mother Kuan Khan Yin for their support and encouragement.

I certify that an Examination Committee has met on 25th May 2006 to conduct the final examination of Chan Chee Sheng on his Doctor of Philosophy thesis entitled "Spatial Apparent Electrical Conductivity of Paddy Soil as an Indicator of Rice Productivity" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Ir. Mohamed Daud, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ahmad Husni Mohd Hanif, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Ir. Desa Ahmad, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Sakae Shibusawa, PhD
Professor
Faculty of Agriculture
Tokyo University of Agriculture and Technology, Japan
(External Examiner)

HASANAH MOHD GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Ir. Mohd Amin Mohd Soom, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ir. Lee Teang Shui, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohammud Che Husain, PhD
Strategic Resources Research Center
Malaysia Agricultural Research and Development Institute
(Member)

_____
AINI IDERIS, PhD
Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which has been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

_____

CHAN CHEE SHENG

Date :

TABLE OF CONTENTS

			Page
ABSTRACT			ii
ABSTRAK			iv
ACKNOWLEDGEMENTS			vi
APPROVAL			vii
DECLARATION			ix
LIST OF TABLES			xiii
LIST OF FIGURES			xiv
LIST OF ABBREVIATIONS			xv
CHAPTER			
1	INTRODUCTION		
	1.1	General Introduction	
1.1			
	1.2	Statement of the Problem	1.5
	1.3	Objectives of the Study	1.6
	1.4	Scopes of the Study	1.7
	1.5	Organization of the Thesis	1.7
2	LITERATURE REVIEW		
	2.1	General	2.1
	2.2	Contact and Non-contact Soil ECa Measurements	
2.2			
	2.3	Comparison of EMI and Direct Contact Methods	2.3
	2.4	Principle and Theory of Veris 3100	2.6
	2.5	Accuracy Issues of Soil ECa Measurements	
2.9			
		2.5.1 Soil Contact	2.10
		2.5.2 Field Condition	2.11
		2.5.3 Pulling Speed	2.11
		2.5.4 Pulling Vehicle	2.12
		2.5.5 Swath Width and Navigation	
2.12			
	2.6	Normalising Data	2.12
		2.6.1 Normalizing Soil ECa Data	2.13
		2.6.2 Normalizing Yield Data	2.14
	2.7	Precision Agriculture	
2.14			
	2.8	Technologies of Precision Agriculture	2.16
		2.8.1 Global Positioning System	2.17
		2.8.2 Geographical Information System	2.18
		2.8.3 Management Information System	2.18
		2.8.4 Decision support system and Treatment Maps	2.19

2.8.5 Future Trends of Precision Agriculture 2.20
2.9 Contributory Factors in Soil ECa Measurements 2.20
2.9.1 Soil Salinity 2.22
2.9.2 Soil Texture 2.22
2.9.3 Soil Moisture 2.23
2.9.4 Bulk Density 2.23
2.9.5 Organic Matter and Cation Exchange Capacity 2.24
2.9.6 Soil Depth 2.24
2.9.7 Soil Temperature 2.24
2.10 Current Applications of Soil ECa in Agriculture 2.25
2.10.1 Characterizing Soil Properties 2.25
2.10.2 Prediction of Crop Productivity 2.27
2.10.3 Measurements of Claypan Soils 2.29
2.10.4 Directed Sampling and Management Zone 2.31
2.10.5 Soil Nutrient Management 2.32
2.10.6 Guide On-farm Trials 2.33
2.10.7 Tool for Precision Farming 2.33
2.10.8 Derived Yield Goals 2.34
2.10.9 Other Uses of ECa Techniques 2.35
2.11 Statistical Analysis and Application 2.37
2.11.1 Gridded or Rasterized Experimental Data 2.37
2.11.2 Methods of Statistical Analysis 2.38

3 MATERIALS AND METHODS
3.1 Study Areas 3.1
3.1.1 Single Plane Large Contiguous Plot 3.3
3.1.2 Subsurface Drainage Plot 3.7
3.2 Research Approach 3.9
3.3 Interpretation of the Veris ECa Data 3.12
3.4 Analyses Methodology Adopted 3.13
3.5 Methods of Statistical Analysis and Application 3.14

4 RESULTS AND DISCUSSION
4.1 Farm Productivity Differences and Soil ECa 4.1
4.2 Soil ECa Measurements 4.2
4.3 Spatial Topographic and Soil ECa Maps of Study Areas 4.3
4.3.1 Spatial Soil ECa of 9-ha Plot 4.3
4.3.2 Spatial Soil ECa of Subsurface Drainage Plot 4.6
4.4 Analyses of Soil Properties 4.9

4.4.1 The 9-ha Plot 4.9
4.4.2 The Subsurface Drainage Plot 4.11
4.5 Correlation of Laboratory EC and Soil ECa 4.13
4.6 Correlation of Grain Yield with Soil Parameters 4.15
4.6.1 The 9-ha Plot 4.15
4.6.2 The Subsurface Drainage Plot 4.17
4.7 Correlation of Soil ECa with Soil Parameters 4.18
4.7.1 The 9-ha Plot 4.18
4.7.2 The Subsurface Drainage Plot 4.18
4.8 Correlation of Soil ECa and Measurement Date 4.19
4.9 Correlation of Shallow and Deep Soil ECa 4.20
4.10 Detection of Outliers 4.21
4.11 Developing the Relationship of Yield to Soil ECa 4.22
4.12 Interpreting the Relationship of Yield to Soil ECa 4.25
4.13 Technique to analyze Paddy Soil Productivity 4.30
4.14 Analysis of Variance 4.36
4.15 Technique for Yield Enhancement 4.39
4.16 Economic Analysis 4.40

5 CONCLUSION 5.1

REFERENCES/BIBLIOGRAPHY R.1
APPENDICES A.1
BIODATA OF THE AUTHOR B.1

LIST OF TABLES

Table		Page
3.1	Field Surface Configuration before and after Three Attempts of Land Levelling	3.4
4.1	Soil Properties of 9-ha Plot before Land Consolidation	4.10
4.2	Soil Properties and ECa of 9-ha Plot after Land Consolidation	4.11
4.3	Soil Properties and ECa of Subsurface Drainage Plot	4.12
4.4	Correlation Coefficients (r) between Grain Yield and Soil Parameters of 9-ha Plot	4.16
4.5	Correlation Coefficients (r) between Grain Yield and Soil Parameters of Subsurface Drainage Plot	4.17
4.6	Correlation Coefficients (r) between Soil ECa and Soil Parameters of 9-ha Plot	4.18
4.7	Correlation Coefficients (r) between Soil ECa and Soil Parameters of Subsurface Drainage Plot	4.19
4.8	Correlation Coefficients (r) between ECa and measurement Dates	4.20
4.9	Correlation Coefficients (r) between Shallow and Deep ECa	4.21
4.10	Grubbs' test statistics of outlier analysis for ECa and grain yield datasets	4.21
4.11	Boundary Line Regression Parameters and Statistics for 9-ha Plot	4.27
4.12	Descriptive Statistics of Yield Derived from Boundary-line Analysis	4.28
4.13	Classification of 9-ha Plot Based on Normalized Values of Predicted Yield (Ypo) and Observed Yield (Yob)	4.32
4.14	Analysis of Variance for Fertility Index and Fertilizer Level Interaction Study Main-season 04/05	4.36
4.15	Yield Performance from (Fertility Index x Fertility Level) Interaction Study at MARDI Seberang Perai, Main-season 04/05 of Table 4.14	4.38

LIST OF FIGURES

Figure		Page
2.1	Veris 3100 Soil Electrical Conductivity Mapping System	2.8
2.2	The System Elements of Precision Agriculture	2.16
3.1	Mean Annual Rainfall at MARDI, Seberang Perai (1990-2000)	3.2
3.2	Location of the Two Study Plots at MARDI, Seberang Perai	3.2
3.3	Field Level before Land Levelling (2000)	3.9
3.4	Field Level after Further Levelling (2001)	3.9
3.5	Field Level a Year after Final Levelling (2002)	3.10
3.6	Layout of Subsurface Drainage Plot at MARDI, Seberang Perai	3.14
3.7	Detail Cross Section of Subsurface Corrugated Draincoil Installation	3.15
4.1	A Global Positioning System Mounted on Veris 3100 Unit Attached To a Tractor Set for Soil ECa Measurements at Mardi, Seberang Perai	4.2
4.2	Typical Pattern of Tractor Passes Used to Measure Soil ECa within the 9-ha Plot at Mardi, Seberang Perai	4.4
4.3	Soil ECa Measurements Obtained with Veris 3100 for Both Shallow (Left) and Deep (Right) Readings for Off-season 02 on the 9-ha Plot at Mardi, Seberang Perai	4.4
4.4	Soil ECa Measurements Obtained with Veris 3100 for Both Shallow (Left) and Deep (Right) Readings for Off-season 03 on the 9-ha Plot at Mardi, Seberang Perai	4.5
4.5	Spatial ECa Maps Obtained with Veris 3100 Readings on the 9-ha Plot at Mardi, Seberang Perai	4.5
4.6	Typical Pattern of Tractor Passes Used to Measure Soil ECa within the Subsurface Drainage Plot at Mardi, Seberang Perai	4.7
4.7	Soil ECa Maps of the Subsurface Drainage Plot at Mardi, Seberang Perai	4.8

4.8 Spatial Soil ECa Three-dimensional Maps of the Subsurface Drainage Plot at Mardi, Seberang Perai 4.8

4.9 Scatter Plots of Laboratory EC versus ECa of 9-ha (Left) and Subsurface Drainage (Right) Plots for Crop Year Off-season 04 4.14

4.10 Scatter Plots of Lab EC versus ECa of 9-ha and Subsurface Drainage (red-colour points) Plots for Crop Year Off-season 04 4.15

4.11 Four Plots that Illustrate How Crop Yield may relate to Soil ECa on Paddy Fields 4.24

4.12 Scatter Plots of Soil ECa and Yield for Crop Year Off-season 02 4.26

4.13 Scatter Plots of Soil ECa and Yield for Crop Year Off-season 03 4.26

4.14 Scatter Plots of Soil ECa and Yield for Crop Year Off-season 04 4.26

4.15 Classification and Layout of 9-ha Plot Based on Predicted Potential Yield and Observed Yields 4.34

4.16 A Typical Scatter Plot of ECa versus Yield with Boundary Line Shown 4.39

4.17 Comparing Extra Sales from Extra Inputs for Various Fertilizer Treatments 4.40

LIST OF ABBREVIATIONS

PA	**Precision Agriculture**
GPS	**Global Positioning System**
EC	**Electrical Conductivity**
ECa	**Apparent Electrical Conductivity**
GIS	**Geographical Information System**
MARDI	**Malaysia Agricultural Research and Development Institute**
DGPS	**Differential Global Positioning System**
hp	**Horse Power**
CCT	**Crop Cutting Test**
N	**Nitrogen**
P	**Phosphorus**
K	**Potassium**
CEC	**Cation Exchange Capacity**
Ca	**Calcium**
OC	**Organic Carbon**
OM	**Organic Matter**
Mg	**Magnesium**
EMI	**Electromagnetic Induction**
mS/m	**MilliSiemens per Meter**
dS/m	**DeciSiemens per Meter**
MIS	**Management Information System**
DSS	**Decision Support System**
IT	**Information Technology**

NH_4	**Ammonia**
H	**Hydrogen**
CA	**California**
r	**Coefficient of Correlation**
LSU	**Louisiana State University**
DID	**Drainage and Irrigation Department**
HDPE	**High Density Polythene**
I	**Electrical Current**
V	**Voltage**
R	**Resistance**
ρ	**Resistivity**
d	**Distance**
C	**Conductivity**
χ	**Conductivity**
OS	**Off-season**
MS	**Main-season**
ppm	**Part Per Million**
me	**Mole Equivalent**
CV	**Coefficient of Variance**
P	**Probability Level**
B	**Boron**
Ypo	**Potential Yield**
Yob	**Observed Yield**
a	**Lower Limit of Yield**

b	**Height of the Peak above a**
c	**The Peak ECa calue**
d	**Curve-fitting Parameter**
N	**Total number of Observations**
n	**Number of observations for log-normal fitting**