



UNIVERSITI PUTRA MALAYSIA

**DRYING PROPERTIES AND RICE PRODUCTION POTENTIAL OF
CRACKING SOILS IN THE MUDA IRRIGATION SCHEME**

MD. TARIFUL ISLAM

FP 1999 5

**DRYING PROPERTIES AND RICE PRODUCTION POTENTIAL OF
CRACKING SOILS IN THE MUDA IRRIGATION SCHEME**

BY

MD. TARIFUL ISLAM

**Thesis Submitted in Fulfilment of the Requirements for the Degree
of Doctor of Philosophy in the Faculty of Agriculture
Universiti Putra Malaysia**

December 1999



**“Dedicated to
My Parents ”**



ACKNOWLEDGEMENTS

The author gives praises to the almighty Allah for leading him to get this far and making all these possible.

The author is pleased to express his respect, deepest sense of gratitude and immense indebtedness to Professor Dr. Wan Sulaiman Wan Harun, Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia (UPM), and Chairman of the Advisory Committee for his guidance, valuable suggestions, encouragement throughout the study period and in preparing this thesis.

The author sincerely expresses his heartfelt gratitude to the Members of the Advisory Committee, Associate Professor Dr. Rajan Amartalingam, Department of Crop Science, Faculty of Agriculture, and Associate Professor Dr. Desa Ahmad, Department of Biological and Agricultural Engineering, Faculty of Engineering, UPM for their immense help, suggestions for successful completion of the research work and making constructive criticism in preparing the thesis.

The financial support provided by the National Council for Scientific Research and Development IRPA (Intensification of Research in Priority Areas) Grant No. 01-02-04-205 is gratefully acknowledged.

The author expresses his deepest gratitude and acknowledges to Dr. Surjit Singh, former Associate Professor of the Department of Agronomy, Faculty of Agriculture, Universiti Putra Malaysia, for his kind guidance as a committee



member at the beginning of this study. The author also expresses his deepest gratitude and acknowledges to Dr. Mohammad Abdul Quayum, Associate Professor, Department of English, Faculty of Modern Language, Universiti Putra Malaysia for his editorial suggestions.

The author likes to extend grateful thanks to Mr. Ho Nai Kin, Senior Agricultural Officer, Mr. Eow Boon Tiak, Irrigation Engineer, other technical and field staff of MADA, and farmers who helped him to conduct the field study at MADA.

The author acknowledges his sincere thanks to the Laboratory Assistants (Mr. Mokhtar Mustapar, Mohd. Hanif Arshad, Ab Aziz Abdullah, and Ariffin Abu Hassan) of Soil Physics Laboratory for their ceaseless help to pursue the research work, experimental data analysis and in preparing this manuscript.

The author expresses his immenses indebtedness, deepest sense of gratitude and profound respect to his parents, brothers, and sisters for their blessings, sacrifice, understanding and encouragement for higher study.

The author takes this opportunity to express his sincere thanks to his colleagues, friends, course mates and well wishers for encouraging him during the period of the study. The author is also grateful to many others, whose names do not appear here, who helped him in the field and laboratory during the study period. The space here is not enough to mention them individually.



Statement of Originality

Except where specific acknowledgement is given, this research work is reported in this thesis is entirely that of the author.



(Md. Tariful Islam)

Date: 23.12.99

I certify that an Examination Committee has met on 11 December, 1999 to conduct the final examination of Md. Tariful Islam, on his Doctor of Philosophy thesis entitled "Drying Properties and Rice Production Potential of Cracking Soils in the Muda Irrigation Scheme" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommended that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

SHAMSHUDDIN JUSOP, Ph.D.

Professor/ Deputy Dean
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

WAN SULAIMAN WAN HARUN, Ph.D.

Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

RAJAN AMARTALINGAM, Ph.D.

Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

DESA AHMAD, Ph.D.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

TO PHUC TUONG, Ph.D.

Water Management Engineer
Soil and Water Sciences Division
International Rice Research Institute
Box 3127, Makati City 1271, Philippines
(External Examiner)



MOHD. GHAZALI MOHAYIDIN, Ph.D.

Professor/ Deputy Dean of Graduate School
Universiti Putra Malaysia

Date: 24 DEC 1999



This thesis was submitted to the Senate of Universiti Putra Malaysia and was accepted as fulfillment of the requirements for the degree of Doctor of Philosophy.


KAMIS AWANG, Ph.D.
Associate Professor/ Dean of Graduate School
Universiti Putra Malaysia

Date: **4 JAN 2000**



TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	viii
LIST OF FIGURES	x
ABSTRACT	xiii
ABSTRAK	xv
 CHAPTER	
I GENERAL INTRODUCTION	1
1.1 General introduction	1
1.2 Objectives of this study	7
1.3 Chapter introduction	8
II REVIEW OF LITERATURE	9
2.1 Variability in soil properties	9
2.2 Clay mineralogy	10
2.3 Soil puddling	13
2.4 Soil shrinkage	16
2.5 Soil cracking	20
2.6 Re-wetting, bypass flow, and bypass ratio	24
2.7 Rice and weather	28
2.8 Scenarios of future climate	31
2.9 Impact of climate change	32
2.10 Effect of drought stress on rice	37
2.11 Need for this study	39
III MATERIALS AND METHODS	42
3.1 Site and soil description	42
3.1.1 Site	42
3.1.2 Rice soils	46
3.1.3 Physico-chemical characteristics	51
3.2 Soil characterization	53
3.2.1 Soil sampling for characterization	53
3.2.2 Clay mineralogy	53
3.2.3 Physical properties	59
3.2.3.1 Soil organic matter	59
3.2.3.2 Particle size analysis	59
3.2.3.3 Bulk density	60
3.2.3.4 Water retention characteristics	61
3.2.3.5 Saturated hydraulic conductivity	62



3.3 Experiment I: Shrinkage Characteristic	63
3.3.1 Volumetric shrinkage (VS) and linear shrinkage (LS)	63
3.3.2 Shrinkage geometry factor (<i>rs</i>)	69
3.4 Experiment II: Soil Drying and Re-wetting	74
3.4.1 Soil drying	74
3.4.2 Re-wetting	76
3.5 Experiment III: Cracking and Bypass Flow	77
3.5.1 Theory and calculation of soil cracking	77
3.5.2 Measurements of crack depth, width, area and volume	81
3.5.3 Computation of water flow components	83
3.6 Experiment IV: Simulation Study	85
3.6.1 Description of the model, ORYZA_W	85
3.6.2 Simulation at production level I	88
3.6.2.1 Simulated sowing dates	88
3.6.2.2 Scenarios of future climate	88
3.6.3 Simulation at production level II	91
IV RESULTS AND DISCUSSION	92
4.1 Soil Characterization	92
4.1.1 Clay mineralogy	92
4.1.2 Physical properties	94
4.1.2.1 Soil organic matter	94
4.1.2.2 Soil texture	96
4.1.2.3 Bulk density	97
4.1.2.4 Water retention characteristics	98
4.1.2.5 Hydraulic conductivity	100
4.2 Shrinkage Characteristics	101
4.2.1 Comparison of methods and Volumetric and linear shrinkage	101
4.2.2 Geometry factor, <i>rs</i>	106
4.3 Soil Drying and Re-wetting	109
4.3.1 Soil drying in the glasshouse and field	109
4.3.2 Re-wetting	118
4.4 Crack and Bypass Flow	121
4.4.1 Crack area, width, depth, length, and volumes	121
4.4.2 Regression analysis	131
4.4.3 Quantification of bypass flow and ratios	132
4.5 Simulation Study (at production level I)	136
4.5.1 Effect of sowing times on potential yield	136
4.5.2 Rice production under different climate change scenarios	147
4.5.3 Simulation at production level II (Drought effect on rice production)	158



V	GENERAL DISCUSSION AND CONCLUSION	162
	BIBLIOGRAPHY	172
	APPENDIX	
	A. Crop Data File	197
	B. Soil Data File	202
	C. Weather Data File	205
	D. Timer Data File	206
	E. XRDs of the Chengai, Tebengau, and Tualang Series	208
	PUBLICATIONS FROM THIS STUDY	217
	VITA	218



LIST OF TABLES

Table		Page
1	Physico-chemical Properties of the Chengai, Tebengau, and Tualang series	52
2	Spacings of First and Second-order X-ray Diffraction Peak Heights of Selected Clay Minerals	54
3	Effect of Pretreatments on the d-Spacings of Selected Clay Minerals	55
4	Major Features of the Three GCMs Used in this Study	89
5	Climate Change Scenarios for the Muda Region	90
6	Soil Organic Matter (%) of Topsoil, Hardpan, and Subsoil Layers of the Chengai, Tebengau, and Tualang Series	95
7	Particle Size of Topsoil, Hardpan, and Subsoil Layers of the Chengai, Tebengau and Tualang Series	97
8	Bulk Density (g cm^{-3}) of Topsoil, Hardpan and Subsoil Layers of the Chengai, Tebengau, and Tualang Series Soils	98
9	Water Retention at different Pressures and Available water for three Layers of the Chengai, Tebengau, and Tualang Series	99
10	Saturated Hydraulic Conductivity (cm d^{-1}) for three Layers of the Chengai, Tebengau, and Tualang Series	100
11	Volumetric and Linear Shrinkage of three Layers of the Chengai, Tebengau, and Tualang Series Soils	103
12	Shrinkage Geometry (rs), Subsidence (dz) and Crack Volume ($dVcr$) for Topsoil, Hardpan, and Subsoil Layers of three Soil Series.....	108
13	Crack Depths (cm) Measured by the Paint Method of three Soil Series.....	128
14	Crack Volume for Rectangular, Triangular, and Square Root Shape Models at Different Days after DOW of three Soil Series	130



15	Water Balance Components for Land Soaking of three Soil Series.....	132
----	--	-----



LIST OF FIGURES

Figure		Page
1	Location of Kedah State in Peninsular Malaysia	43
2	Map Showing the Study Areas in the Chengai, Tebengau And Tualang Series	47
3	Isotropic Shrinkage of Soil Cube with Initial Layer Thickness, z (cm) and Volume V (cm ³) to a Cube with Volume, $V-\Delta V$ (cm ³) and Sides, $z-\Delta z$ (cm)	73
4	Vertical Cross-section through a Crack, Showing Rectangular, Square Root, and Triangular Shapes	77
5	Linkage between the Modules ORYZA1, PADDY, and DSTRESS (After Wopereis, 1993)	87
6	Relationship Between the Sand and Wax Methods for Volumetric Shrinkage	104
7	Relationship Between the Sand and Wax Methods for Linear Shrinkage	105
8	Moisture Profile at Different Depths During Drying of the Chengai, Tebengau, and Tualang Series Soils	111
9	Soil Water Potential at Different Depths During Drying of the Chengai, Tebengau, and Tualang Series Soils	111
10	Moisture Profile at Different Depths During Drying (2 weeks after DOW) of the Chengai, Tebengau, and Tualang Series Soils	114
11	Moisture Profile at Different Depths During Drying (8 weeks after DOW) of the Chengai, Tebengau, and Tualang Series Soils	115
12	Bulk Density of the Chengai, Tebengau, and Tualang Series Soils (2 weeks after DOW)	117
13	Bulk Density of the Chengai, Tebengau, and Tualang Series Soils (8 weeks after DOW)	117



14	Water uptake During Re-wetting in Soil Clods of Topsoil, Hardpan, and Subsoil of three Soil Series	119
15	Crack Width at Different Days after DOW for three Series	127
16	Crack Depth at Different Days after DOW for three Series	128
17	Crack Area at Different Days after DOW for three Series	129
18	Crack Length at Different Days after DOW for three Series	129
19	Relationship Between D-S Model and R-V Model Calculated Crack Volume of three Series	131
20	Eighteen-year Mean Weekly Radiation in the Total Cropping Period for the Off Season	141
21	Eighteen-year Mean Weekly Radiation in the Total Cropping Period for the Main Season	141
22	Eighteen-year Mean Weekly Temperature in the Total Cropping Period for the Off Season	142
23	Eighteen-year Mean Weekly Temperature in the Total Cropping Period for the Main Season	142
24	Crop Duration (TGP) at Different Sowing Dates in the Main and Off Season	143
25	Weight of Above Ground Dry Matter (WAG) at Different Sowing Dates in the Main and Off Season	143
26	Maximum Leaf Area Index (LAI) at Different Sowing Dates in the Main and Off Season	144
27	Grain Yield (WRR14) at Different Sowing Dates in the Main and Off Season	144
28	Simulated Rice Yield at 20%, 40%, 60%, 80%, and 100% Probability Levels for Different Sowing Dates (Off Season)	145
29	Simulated Rice Yield at 20%, 40%, 60%, 80%, and 100%Probability Levels for Different Sowing Dates (Main Season)	145



30	Actual and Simulated Yields (70 DOY) from 1981-1995 (Off Season)	146
31	Actual and Simulated Yields (217 DOY) from 1981-1995 (Main Season)	146
32	Total Growing Period under Different Climate Change Scenarios	155
33	Maximum Leaf Area Index (LAI) under Different Climate Change Scenarios	156
34	Dry Matter Weight (WAG) under Different Climate Change Scenarios	156
35	Yield (WRR14) under Different Climate Change Scenarios	157
36	Net Water Use (NWU) under Different Climate Change Scenarios	157
37	Drought Effect on Crop Duration at Different Stages in the Off and Main Seasons	161
38	Drought Effect on Rice Yield (WRR14) at Different Stages in the Off and Main Seasons	161
39	The XRDs of the Topsoil, Hardpan, and Subsoil of the Chengai Series	208
40	The XRDs of the Topsoil, Hardpan, and Subsoil of the Tebengau Series	211
41	The XRDs of the Topsoil, Hardpan, and Subsoil of the Tualang Series	214



Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the Degree of Doctor of Philosophy.

**DRYING PROPERTIES AND POTENTIAL RICE PRODUCTION OF
CRACKING SOILS IN THE MUDA IRRIGATION SCHEME**

By

MD. TARIFUL ISLAM

December 1999

Chairman: Professor Dr. Wan Sulaiman Wan Harun

Faculty: Agriculture

Three previously puddled rice soils, namely the Chengai, Tebengau, and Tualang series of the Muda Irrigation Scheme were studied both in the field and in the glass house. The objectives of this study were to understand the processes of drying, cracking and re-wetting and relate these to soil properties, to develop a simple model for estimating bypass flow and bypass ratio of cracking soil during land soaking, and to simulate the ORYZA_W model for determining the optimum sowing date, quantifying rice yield, net water use, and crop duration under future climate change scenarios, and assessing the drought effect on irrigated rice yield. Calculated volumetric and linear shrinkage of the Chengai and Tebengau series were similar and greater than those of the Tualang series. The measured shrinkage geometric factor r_s , with values of around 3, indicated that shrinkage of these three series was isotropic. Comparatively faster moisture depletion and absorption were observed in the Chengai and Tebengau series than in the Tualang series both in the glasshouse and field conditions. Chengai and Tebengau soils showed similar crack width, depth, area, length and volume, these properties being significantly different from those of the Tualang soil. The deepest



crack depth below the puddled layer measured by the paint method were 77, 73, and 52 cm in the Chengai, Tebengau, and Tualang series, respectively. A model was developed to quantify bypass flow during land soaking. According to the model, the amount of water that bypassed the topsoil of the three soil series accounted for 59-67% of total input water. Higher yields (10.2 to 10.6 t ha⁻¹) were predicted for the off season (56-98 Day of the Year - DOY) than the main season (9.2 to 9.7 t ha⁻¹ during 196-238 DOY). The higher off season yields were associated with higher radiation and longer crop duration. The impact of 15 different climatic scenarios was evaluated. Crop duration (TGP) was shortened by 3 and 2 days during the off and main seasons, respectively, following a 4^oC increase in the daily maximum temperature. Increased CO₂ levels predicted an increase in yield in both seasons. The combinations of increased CO₂ levels and temperatures predicted increased yields for both seasons. The scenarios of three General Circulation Models (GCM) predicted yield reduction in the off season while in the main season, predicted yields were almost similar to current yields. The net water use (NWU) increased with increase in temperature in both seasons for all cases. Increments in CO₂ level did not predict any change for NWU in both seasons. The combinations of increased temperatures and CO₂ levels, and the scenarios of three GCMs predicted an increase of NWU in both seasons. Increased NWU was mainly influenced by temperature increments. Yield differences between crops temporarily stressed at mid-tillering and panicle initiation stages and non-stressed crops were smaller. However, maturity was delayed in both seasons. Large yield reductions were predicted for temporary drought stress at the flowering stage, while maturity was delayed by 3 and 1-day in the off and main seasons, respectively.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah.

**CIRI-CIRI PENGERINGAN DAN POTENSI PENGELUARAN PADI PADA
TANAH MEREKAH DI SKIM PENGAIRAN MUDA**

Oleh

MD. TARIFUL ISLAM

Disember 1999

Pengerusi: Profesor Dr. Wan Sulaiman Wan Harun

Fakulti: Pertanian

Tiga siri tanah padi, iaitu, siri Chengai, Tebengau, dan Tualang telah dikaji di ladang dan juga di rumah kaca. Tujuan kajian ini dijalankan adalah untuk: 1) memahami proses pengeringan, rekahan dan pembasahan semula dan menghubungkaitkannya dengan ciri-ciri tanah, 2) menghasilkan satu model ringkas untuk menganggarkan aliran pirau (bypass flow) dan nisbah pirau (bypass ratio) tanah yang merekah semasa pembasahan, dan 3) membuat simulasi model ORYZA.W untuk menentukan masa optimum untuk menyemai, untuk menentukan hasil padi, penggunaan air, dan ketahanan tanaman dibawah cuaca yang sering berubah, dan untuk menilai kesan kemarau keatas padi yang di tanam dengan bantuan pengairan. Kiraan volumetrik dan kecutan lurus (linear shrinkage) untuk siri Chengai dan Tebengau adalah sama dan lebih tinggi dari siri Tualang. Nilai faktor r_s , iaitu geometri kecutan (shrinkage geometry) pada tahap 3 menunjukkan pengecutan tanah pada tiga siri tanah tersebut adalah isotropik. Susutan kelembapan dan penyerapan yang lebih cepat dilihat pada siri Chengai dan Tebengau berbanding dengan siri Tualang dalam ujian di rumah kaca dan di ladang. Lebar, kedalaman, panjang dan juga isipadu rekahan pada siri

Chengai dan Tebengau adalah sama dan berbeza jika dibandingkan dengan tanah siri Tualang. Rekahan terdalam di bawah lapisan kedap (puddled) yang dikira dengan menggunakan kaedah cat adalah 77, 73 dan 52 cm pada siri Chengai, Tebengau dan Tualang. Satu model telah dibentuk untuk mengira aliran pirau (bypass flow) semasa pembasahan tanah. Mengikut model ini, jumlah air yang melalui tanah atas pada ketiga-tiga siri tanah tersebut adalah 59-67% dari jumlah keseluruhan air yang diguna. Hasil lebih tinggi (10.2 to 10.6 t ha⁻¹) diramal pada musim pertama (56-98 Day of the Year - DOY) berbanding dengan musim kedua (9.2 to 9.7 t ha⁻¹ pada 196-238 DOY). Ini dikaitkan dengan kadar radiasi yang lebih tinggi dan jangka tanaman yang lebih lama pada musim pertama dibanding dengan musim kedua. Kesan bagi 15 senario cuaca yang berbeza telah dinilai. Jangka masa tanaman (TGP) adalah dipendekkan hingga 3 dan 2 hari semasa musim pertama dan musim kedua berikutan peningkatan sebanyak 4⁰C pada suhu maksimum harian. Penambahan hasil diramalkan bagi peningkatan paras CO₂ dalam kesemua senario pada kedua-dua musim. Kombinasi paras CO₂ dan suhu yang lebih tinggi diramalkan menambahkan hasil pada kedua musim. Senario dengan tiga model edaran umum (General Circulation Model - GCM) menjangkakan pengurangan hasil pada musim pertama manakala pada musim kedua jangkaan hasil adalah hampir sama dengan hasil semasa. Jumlah penggunaan bersih air (NWU) meningkat dengan peningkatan suhu pada kedua-dua musim dalam semua kes. Penambahan paras CO₂ tidak menunjukkan apa-apa perubahan pada NWU dalam kedua-dua musim. Gabungan peningkatan suhu, paras CO₂ dan senario oleh semua model GCM menunjukkan peningkatan NWU dalam kedua-dua musim. Peningkatan NWU dipengaruhi kenaikan suhu. Perbezaan hasil antara tanaman yang mengalami tegasan kemaran pada pertengahan pembilahan (mid tillering) dan peringkat permulaan



panikle dengan yang tidak mengalami tegasan kemaran adalah kecil tetapi kematangan menghadapi dilewatkan pada kedua-dua musim. Pengurangan hasil yang banyak adalah diramalkan bagi keadaan kemarau sementara pada peringkat pembungaan dan kematangan dilewatkan hingga 3 hari pada musim pertama dan 1 hari pada musim kedua.

CHAPTER I

INTRODUCTION

1.1 General Introduction

Rice is grown under diverse climatic, hydrological and edaphic conditions. Based on water regime, four major ecosystems can be distinguished (IRRI, 1989) i.e. i) irrigated, ii) rainfed lowland, iii) upland, and iv) deep water and tidal wetland ecosystems. In lowland ecosystem, water is a major factor as up to 5000 liter of water may be needed to produce 1 kg of rice (Tabal *et al.*, 1992). In irrigated ecosystem, the water availability determines the command area of the irrigation project. Similarly, in rainfed lowland system, rainfall largely determines the attainable yield of rice. Efficient management of soil-water, whether its source is irrigation or rainfall, is thus crucial for global rice production.

The Muda Agricultural Development Authority (MADA) Irrigation Scheme or region, also known as the “rice-bowl” of Malaysia, covers a total gross area of 126,000 ha of which 96,000 ha are under paddy cultivation. The scheme produces around 40% of the total production of rice in Malaysia. The parent



materials of the soils of the irrigation scheme area are mainly marine sediments deposited during the rise in sea level in the Pleistocene era and riverine sediments (Soo, 1972; Kawaguchi and Kyuma, 1969). The soils are rich in montmorillonitic clay, especially those derived from marine sediments (Furukawa, 1976) and in many parts within the scheme, the soils experience cracking upon drying because of their clayey texture.

In clay soils, decrease in the moisture content is accompanied by the reduction in the soil volume. The soil surfaces shrink due to faster moisture dissipation from the soil mass and shrinkage cracks develop. Puddling of soils during land preparation for irrigated rice destroys the aggregates and accentuates the soil cracking upon drying. Soil cracking turns a clay soil into a varying heterogeneous two-phase medium: soil matrix and cracks. When a clay soil dries, three shrinkage phases appear viz. normal shrinkage, residual shrinkage, and zero shrinkage (Bronswijk, 1988; Ishiguro, 1992). Upon re-wetting, the cracked soils swell because of hydration of the expanding clays and tend to regain their original state. But in practice the cracks are not entirely eliminated without physical manipulation such as puddling. This is because cracks occur not just due to electrochemical forces but also due to rearrangement of particles during water loss and hence cannot be reversed. This process of alternate swelling and shrinkage is quite common and has important consequences for the utilisation of clay soils. In

agricultural soils, the main consequence is the rapid transport of water through cracks (bypass flow). Deliberate or unavoidable drying of a previously submerged puddled soil creates soil cracks that may extend through the puddled layer. This may cause a radical change in the seasonal water balance through a tremendous increase in water consumption during land preparation, mainly because of preferential flow down through deep soil cracks (Valera, 1977; IRRI, 1978; Hardjoamidjojo, 1992; Wopereis *et al.*, 1994). Part of rain or irrigation water and dissolved fertilisers flow through cracks to the deeper subsoil by-passing the soil profile and may lead to water stress and nutrient deficiency to the crops (Bouma and Dekker, 1978; German *et al.*, 1984). The impact of this process to the environment is the leaching of solutes through cracks to the subsoil and tile drains, contributing to pollution of groundwater and surface water (Thomas and Phillips, 1979; Coles and Trudgill, 1985). Cracks are especially prominent in soils containing 2:1 type expanding clay minerals, like montmorillonite and vermiculite. However, they may also be clearly noticeable in kaolinitic soils (Moormann and van Breeman, 1978). Ishiguro (1992) observed crack widths of about 2 cm and crack depths of 7 cm to 20 cm measured in puddled rice soil subjected to 20 to 30 days of drying. However, cracks may reach a depth of 65 cm in dry previously puddled montmorillonitic rice soils (Wopereis *et al.*, 1994).

When they are re-wetted with water, the cracks tend to disappear due to swelling and slaking of the soil. The later phenomena decrease the soils' permeability rapidly (Kitamura, 1990). Soil cracking results in not only excessive presaturation water requirement for land preparation but also alter the irrigation and cropping schedules. Onset of drought, occurring commonly once in several years, aggravates the situation of soil cracking and may cause severe loss of rice production in the area due to water shortage. The extent and severity of cracking depends upon some soil physical parameters like the type and amounts of clay, organic matter content and rapidity of moisture depletion from the soil. A mathematical relationship of these parameters with the shrinkage parameters (volumetric shrinkage, shrinkage geometry) would help predict soil cracking and in deciding water management options. Shrinkage characteristics and additional assumptions concerning geometry of swelling and shrinkage, bypass flow, crack volume, and surface subsidence of soils can be calculated.

In cracking soils of the MADA, the width of crack may be 3-12 cm and the depth of crack reaches up to 50-75 cm depth during the dry period (mid January to early April). The geometry of cracks and their effects on bypass flow in the MADA Irrigation Scheme would help better management of the project. The specific problems of the project related to soil water management were: