

SOIL MOISTURE MEASUREMENT USING CAPACITANCE TECHNIQUES

by

S.Khaja Syed Shahul Hameed
Instrument Design Development Center

Submitted

in fulfillment of the requirement of the degree of
Doctor of Philosophy

to the



Indian Institute of Technology, Delhi
India
April 2010

Certificate

This is to certify that the thesis entitled “*Soil Moisture Measurement Using Capacitance Techniques*” submitted by S.Khaja Syed Shahul Hameed for the award of the degree of the **Doctor of Philosophy** to the Indian Institute of Technology, Delhi, is a record of the bonafide research work he has carried out under my supervision. The results contained in this thesis have not been submitted to any other University or Institute for the award of a degree or diploma.

(Shri A.K. Agarwala)
Chief Design Engineer
Instrument Design Development Center
Indian Institute of Technology, Delhi
New Delhi – 110 016
India

ACKNOWLEDGEMENTS

I am deeply indebted and gratefully express my sincere gratitude to my supervisor **Shri.A.K.Agarwala** for his most invaluable guidance, constant source of inspiration, encouragement and support throughout this work, without his unremitting support; this work would have never been completed.

I express my heartfelt and sincere thanks to **Dr.S. Ayyappan, Director General, Indian Council of Agricultural Research, New Delhi** for his humbles and ever willingness to extend all possible help during this period. No amount of words will be sufficient to describe his honest approach for innovation in agricultural research in all fields.

I am extremely grateful to **Dr.K.K.Vass, Director, Central Inland Fisheries Research Institute,(ICAR), Barrackpore** for granting me study leave for enabling this venture.

I am especially grateful to **Prof. A.L.Vyas, Chairman SRC, Prof. A.Ganguli, and Prof. Rakesh Kumar** members of SRC for their constructive and invaluable suggestions during this period.

I am grateful to **Dr.N.K Jain, Head, IDDC** and to the other faculties, staff members and students of the IDDC, for standing by my side through my tiring times and providing immense encouragement and unsolicited support.

I am also thankful to **Mr.V.K.Gandhi** of NMR Lab, IDDC for his help in experimental work.

I would like to earnestly extend my sincere thanks to my friends **Satish Dandhole, Manoj Kumar Singh, P.Pakiam, Rama Shankar, M.D.Selvaraj, S.L.Patil**, for making my stay in IIT an intellectually stimulating environment.

I would finally like to thank all those directly and indirectly involved in the making of this thesis and my research work a success.

KHAJA SYED SHAHUL HAMEED.S

ABSTRACT

The total volume of water on the earth is vast at approximately equal to 1.4 billion km³ but fresh accessible water is less than 1% at approximately 11 million km³[1]. India, with a share of 2.3% of world's land area, and only 4.2% of the water resources supports 16.9% of world population. Therefore, the fresh water resources in India are under stress. In India, nearly 57% of the total land area is under agriculture against the world average of just 11.5%, with a net sown area above 140 million ha and the forest cover of 22.8% against a desirable level of 33% [4]. The slowdown in agriculture is mainly attributed to depletion and deterioration of natural resources like soils and water, improper fertilizer and chemical application, uncontrolled irrigation, water logging and salinization resulting in lack of biological activity in soils. With the existing methodologies, water use efficiency rarely exceeds 40% and the available estimates indicate that by 10% increase in water use efficiency, India can gain more than 50 million tons of food grains from the existing irrigated area. Inefficient use of water also leads to inefficiency of all other inputs such as fertilizer, and chemicals, leading to increase in the cost of production and degradation of fertile soils. Poor use of energy specifically fossil energy increases cost of production, global warming and burden on exchequer, apart from abiotic and biotic stresses aggravate the agriculture sector and hence ideal farming approach shall aim for increase in agricultural production, conservation of soils and improving the productivity of water.

Hence water can no longer be considered as a cheap and plentiful resource; rather it's a scarce resource with an economic value. It is necessary to improve the efficiency of water utilization as most available agricultural methods utilise only about 1/3rd of available water to grow plants.

Demand based irrigation scheduling has not so far been implemented at individual farmer level. However, the availability of reliable and cheaper soil moisture sensors could make this possible. Hence in this work an attempt has been made to make an affordable, easy to operate, handy, low cost and durable soil moisture sensor for use by marginal farmers of India.

CONTENTS

Certificate	i
Acknowledgements	ii
Abstract	iii-iv
Contents	v-x
List of Figures	xi-xiii
List of Tables	xiv
Glossary of Symbols	xv

CHAPTER 1	Page No.
Introduction and Literature Survey	1-23
1.1 Introduction	1
1.2 Background of Soil Moisture Measurement and Its Importance in Agriculture	3
1.2.1 Available Water	8
1.2.2 Unavailable Water	9
1.2.3 Oven Dry Soil	10
1.2.4 Permanent Wilting Point	10
1.2.5 Field Capacity	11
1.2.6 Saturation Capacity	11
1.3.1 Benefits of Irrigation to Agriculture	13

1.3.1.1	Choice of Crops	13
1.3.1.2	Growing High Yielding Varieties	14
1.3.1.3	Fertiliser Application	14
1.3.1.4	Timely Agricultural Operation	15
1.3.1.5	Crop Productivity	15
1.3.1.6	Control of Weed	16
1.3.2	Harmful Effects of Excess Irrigation	16
1.3.2.1	Impaired Soil Aeration	17
1.3.2.2	Imbalance in Nutrient Uptake	17
1.3.2.3	Restricted Root System	17
1.3.2.4	Loss of Soil Fertility	18
1.3.2.5	Soil Erosion	18
1.3.2.6	Production of Harmful Gases	18
1.3.2.7	Activities of Micro Organisms	19
1.4	Scope of the Thesis	19
1.5	Contribution of this Thesis	21
1.6	Thesis Organization	22

CHAPTER 2

An Overview of Soil Moisture Measuring Techniques and Their Shortcomings	24-45	
2.1	Introduction	24
2.2	Literature Survey	24

2.2.1	Operating Frequencies	25
2.2.2	Irrigation Scheduling Based on SMP/SWC	28
2.2.3	Irrigation Scheduling Based on FC/PWP	32
2.3	Electrical Impedance Techniques	36
2.3.1	Resistive Sensor	36
2.3.2	Resistive Sensor (Gypsum)	36
2.3.3	Capacitive Sensor	37
2.4	Gravimetric Techniques	38
2.5	Hygrometric Techniques	38
2.6	Nuclear Techniques	38
2.6.1	Neutron Scattering	38
2.6.2	Gamma Attenuation	39
2.6.3	Nuclear Magnetic Resonance	39
2.7	Optical Methods	39
2.8	Pressure Plate Membrane	40
2.9	Remote Sensing Techniques	40
2.10	Suction Plate Apparatus	41
2.11	Time-Domain Reflectometer (TDR)	42
2.12	Frequency Domain Reflectometer	42
2.13	Amplitude Domain Reflectometer	43
2.14	Tensiometric Techniques	43
2.15	Short Comings	44
2.16	Summary	45

CHAPTER 3

A Novel Low Cost Capacitance Based Soil Moisture Measuring Methodology	46-62
3.1 Introduction	46
3.2 Experimental Procedures	47
3.2.1 Soil Tests	47
3.3 Capacitance based Soil Moisture Sensor	50
3.3.1 Experimental setup	53
3.4 Principle of Operation of Capacitance Sensor	55
3.5 Measurements Performed using Moisture Sensor	58
3.6 Summary	62

CHAPTER 4

Simulation and Experimental Results of Capacitance Based Soil Moisture Measuring Methodology	63-119
4.1 Introduction	63
4.2 Simulation and Experimentation Methodology	64
4.2.1 Pressure Plate Membrane Tests	64
4.2.2 Field Capacity	64
4.2.3 Permanent Wilting Point	64
4.2.4 Frequency of Operation	65
4.3 Simulation and Experimental Results	65
4.3.1 Soil Structural Analysis	66

4.3.2	Pressure Plate Membrane Test	67
4.4	Capacitance-Resistance Response to identify FC	68
4.5	Tensiometer and Capacitance Response Study	71
4.6	Capacitance Response for Concentrated Saline Water	74
4.7	Capacitance Response on simulated NPK enriched Soil	79
4.7.1	Preparation of NPK Enriched Soil	79
4.7.1.1	Sample 1(NPK Enriched)	80
4.7.1.2	Sample 2(NPK Enriched)	81
4.8	Capacitance Response of Simulated Saline Soils	83
4.8.1	Alluvial (Loam) Soil	83
4.8.2	Bengal (Clay) Soil	86
4.8.3	Black (Clay) Soil	89
4.8.4	Capacitance Response on Soil Averages	92
4.8.5	Comparison of Measurements by LCR meter and Agilent Impedance Analyzer	95
4.9	RF Impedance Measurements	99
4.9.1	Alluvial (Loam) Soil	99
4.9.2	Black(Clay) Soil	102
4.9.3	Bengal (Clay) Soil	105
4.9.4	Soil Averages of Alluvial, Black and Bengal Soils	107
4.10	Soil Moisture Sensor and Application to Irrigation	110
4.10.1	Soil Moisture Sensor Operating At 1kHz	110
4.10.2	Summary of Results of RF Measurements	115

4.10.3	Cost of the Proposed Sensor Device	116
4.11	Validation of Results	116
4.12	Summary	118
 CHAPTER 5		
Potential Applications of the Methodology		120-128
5.1	Introduction	120
5.2	Irrigation Scheduling, Saving Irrigation Water, Electricity	121
5.3	Climate Change and GHGs Emissions	122
5.4	Saving Fertile Land becoming Saline, Infertile, Water Logged	126
5.5	Summary	127
 CHAPTER 6		
Conclusion and Future Work		129-131
6.1	Main Conclusions	130
6.2	Possibilities of Future Research	131
References		132-142
Appendix A1		143-144
List of Research Publications during the PhD Program		145
Bio-Sketch of Author		146