DEVELOPMENT OF A NOVEL EVALUATION METHOD FOR WATER MOVEMENT AND RETENTION CHARACTERISTICS THROUGH UNSATURATED POROUS MEDIUMS

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論 文 名　：DEVELOPMENT OF A NOVEL EVALUATION METHOD FOR WATER MOVEMENT AND RETENTION CHARACTERISTICS THROUGH UNSATURATED POROUS MEDIUMS
（不飽和多孔質地盤における水移動および水分保持特性の新しい評価手法の開発とその適用）

区　　分　：甲

論 文 内 容 の 要 旨

Starting in the mid-1900s, global warming has become one of the most serious alarming environmental issues around the world. Scientists have been warning that one of the primary effects of climate change is the disruption of the natural water cycle. It is believed that global warming induces augmentation in the likelihood of more intense droughts and precipitation events. Deserts and drylands form 39 – 45% of the total earth's land and are home to more than 4 billion people, where due to desertification, 12 million hectares are lost every year. Recently arable land is being lost at 30 to 35 times the historical rate, where approximately 1~6% of the drylands inhabitants live in desertified areas. Therefore, providing innovative water management technologies is essential to mitigate land degradation and to combat desertification.

There is a compelling need for evaluating the flow of water through porous mediums and the related surface-atmosphere boundary fluxes, where it directly linked to several practical engineering applications such as prediction of expansive soil behavior and water resources management. The flow of moisture through a soil profile and the related soil-atmosphere fluxes are complex processes that follow ambiguous mechanisms. In general, these processes are mainly controlled by the demand and supply of water which depends on the boundary conditions, the ability of the porous medium to transmit water which is related to the medium retention and permeability characteristics (mainly the Soil Water Characteristics Curve [SWCC] and the Hydraulic Conductivity Function [HCF]), and the vegetation cover. The three factors are highly correlated and act like a closely-coupled system. Accurate, comprehensive, and innovative techniques and methods to evaluate the above-mentioned factors are in great need. This thesis aims at investigating the flow of water through unsaturated porous mediums and the related surface-atmosphere boundary fluxes mainly the evaporation flux. In addition, as a step to combat desertification, the research identifies optimal adaptations for a natural soil cover to enhance water conservation through soil profiles. Four main objectives were delineated to achieve the aforementioned aim, starting with the development of a novel full automatic system utilizing the Continuous Pressurization Method (CPM) that allows concurrent, continuous, direct and accurate determination of the SWCC and the HCF in a short time. To propose a sampling methodology and testing setup that allows for rapid, concurrent, continuous, direct and accurate determination of undisturbed samples SWCC and HCF. To formulate a conceptual framework that elaborates the pore water pressure and suction profile development under transient conditions. To identify the mechanism and dynamics in which the textural contrast boundary and individual layer thickness affect the actual evaporation flux and water storage through double-layered soil profiles. The findings serve as a basis for providing optimal adaptations for a natural soil cover that functions in a way to reduce the actual evaporation rate and maximizes the water conservation capabilities. The thesis was divided into 7 chapters as follows:

Chapter 1, land degradation and desertification are discussed accompanied with statistical records demonstrating the drylands distribution, desertification vulnerable lands, related water scarcity, in addition to some global warming issues and desertification combating concepts. The proposed aim and its vital role in combating desertification, objectives, original contributions and the framework of the thesis are presented.

Chapter 2 provides a brief literature review illustrating the research that has been carried out in relation to the scopes considered in this thesis. The chapter is divided into three main sections, where the first section discusses the recently reported work considering the SWCC, while the second and third sections deal with the HCF and the evaporation flux issues.

Chapter 3 presents the development of a novel SWCC determination technique and system utilizing the CPM. The theory, assumptions, experimental setup, testing methodology, validation of the system, accuracy, repeatability, advantages, and limitations of the developed system are thoroughly discussed. It was found that regardless of the applied air pressurization rate, the accuracy, precision, reliability, and repeatability of the developed CPM system were confirmed. In addition, using the developed CPM system, the SWCC can be obtained in less than 9% of the time required using the conventional Multi-Step Flow Method (MSFM).

Chapter 4 presents the development of the direct, rapid, and concurrent SWCC and HCF determination CPM based system. The theory, assumptions, experimental setup, testing methodology, validation of the system, accuracy, repeatability, advantages, and limitations of the developed system are thoroughly discussed. In addition, the pore water pressure and the matric suction profiles redistribution under transient conditions (CPM) are investigated. It was confirmed that the developed system is accurate with precise repeatability, reliable, direct, and requires short time that allows concurrent determination of the SWCC and HCF. However, a proper evaluation of the Ceramic Disk's (CD) impedance on the driving hydraulic head gradient is necessary. The SWCC and the HCF were concurrently obtained in a remarkably short time which accounts for less than 7% of the time required using the conventional methods.

Chapter 5 focuses on the development of a sampling methodology and a novel full automatic system adopting the CPM that allows for continuous and accurate determination of undisturbed samples SWCC and HCF in a very short time. The theory, assumptions, experimental setup, testing methodology, validation of the system, accuracy, repeatability, advantages, and, limitations of the developed system are presented. In addition, the reliability and discrepancies resulting from adopting remolded samples are discussed thoroughly, accompanied by a numerical confirmation. It was found that remolded samples do not properly represent the in-situ conditions with significant discrepancies that should be carefully considered when conducting analysis and proposing countermeasures against unsaturated soil related Geo-disasters. In addition, the reliability of the proposed undisturbed sampling and testing methodology was confirmed.

Chapter 6 presents the mechanism and dynamics in which the textural contrast boundary and individual layer thickness affect the actual evaporation rate and water storage through double-layered soil profiles. Finally, an optimal natural soil cover that functions in a way to reduce the actual evaporation rate and maximizes the water conservation capabilities was proposed. It was found that regardless of the sequence of layering in double-layered soil profiles, configurations with small ratio (the top layer to the bottom layer residual water content ratio multiplied by the top layer to the bottom layer thicknesses ratio) exhibit higher water conservation capability during SII. Generally, it was found that the shallower the textural contrast boundary results in higher water conservation capabilities during the first and second stages of evaporation.

Chapter 7 summarizes the main findings of this dissertation and delineates the future work.