学　位　論　文　要　旨

Capillary-based Subsurface Irrigation System for Water-saving Agriculture
毛管現象を利用した節水地下灌漑システム

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Fresh water deficit will become crucial and the world will face the crisis in the next 10 years when the world population exceeds 8 billion. Agricultural activities which consume more than 70% of the available water are in great threat from competition with industrial and domestic use. However least efforts have been done to reduce water usage and practice water-saving in agriculture compared to the industrial and domestic because of the abundant available of this resource in many arable land. The irrigation management practices however are still advancing with newer technologies with higher efficiency. The aim of this study is to investigate the feasibility of the fibrous-capillary system for water-saving irrigation system. Capillary irrigation has a great potential to save water in agriculture because water is supplied directly into the rooting zone by the gradient of soil water potential caused by plant water uptake. An advancement of the capillary irrigation system is being introduced in this study in which a fibrous material is used as an interface to transport water from reservoir into the rooting zone. Water that flow in this system is managed by capillary action. A nonwoven fibrous sheet or a geo-textile system with high capillarity is used as the interface material. Water can be transported easily within the soil area using the fibrous system by the capillary flow. Infiltration into the soil from the fibrous system is at the soil natural absorption rate, thus creating a uniform wetting pattern by matching the soil capillary absorption properties. This allows the soil to absorb water as needed at a slower and more effective rate. On the other hand, plant uptake water freely from the wetted soil for transpiration. As the potential gradient increases, the water flow continues from the reservoir through the fibrous to replenish the deficit. The continuous water supply will sustain the soil-plant evapotranspiration at very minimum stress. This process is regarded as a plant-based irrigation system, which is being emphasized in this study in a new irrigation system. The control of the fibrous-capillary system is done by manipulating

the distance between the interface of the soil-fibrous to the water in the reservoir known as water supply depth. Manipulation of the depth will affect the capillary flow through the fibrous thus changing the irrigation volume rate. As the result the plant evapotranspiration will be affected. An optimal water supply depth will ensure sufficient water supply to the plant for healthy growth while minimizing the evaporation from the soil.

Experiments were conducted, by using the fibrous-capillary system apparatus built in a cylindrical and a rectangular container. A small reservoir with an adjustable water level controller was located under the container. A vertical fibrous sheet used to transfer the water was position on the container floor and buried in the soil. The other end of the vertical fibrous was immersed in the reservoir. A closed-climate chamber and a phytotron were used to conduct experiments related to water flow and plant water uptake. The results revealed the dynamics of water flow and soil moisture condition in the fibrous-capillary system which was largely affected by the climatic change and the plant growth stages. Moreover the dynamics were also affected by the change of water supply depth where the advancement of wetting front, soil water content and the cumulative infiltration were almost proportional to the decreased of the depth. This phenomenon was modeled by using a soil-plant-atmosphere-continuum (SPAC) approach and a modified version of the SPAC model was introduced. The time-space variation of water flow and wetting pattern in the fibrous-capillary system was successfully simulated and visualized based on Richard equation using HYDRUS. An adaptive strategy is proposed to control this irrigation system in order to adapt the dynamic need of water by the plant at various growth stages has shown very substantial results in water-saving strategy.

This study has contributed to a new cultivation management strategy by water-saving irrigation system in which the system will significantly reduce the input cost and increase the profit. Proper utilization of the system and management assures better plant quality with less water by maintaining near perfect air/water content in the soil. All chemicals that may go through the system directly into the rooting zone shall result in excellence plant health with substantially less fertilizers by eliminating surface exposure which reducing harmful and wasteful run-off. The system offers a great technology for industry to develop a new water-saving irrigation system. The originalities of this study lies on the mechanism to transport water directly into the rooting zone by using the fibrous-capillary system and the measuring-control method for detecting plant water demand and supplying the accurate amount based on the detected demand.