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SUMMARY OF DOCTORAL THESIS

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Title: New Scheme to Optimize Irrigation Depths Using a Numerical Model of Crop Response to Irrigation and Quantitative Weather Forecast
(作物の灌漑への応答の数値モデルと数値天気予報を利用した灌漑水量の新しい最適化法)

With increasing scarcity and growing competition for water, irrigation managers should adopt new approaches for irrigation scheduling to sustain crop production, and thereby maximize net income. About two thirds of irrigated farms are located in developing countries which are the main source of food production. With advances in computer technology and theory in soil physics, the use of numerical models can be an important tool to simulate crop water behavior under different conditions of water supply. It can also simulate water flow in the root zone and crop growth and is useful tool for extrapolating findings from field studies to conditions not tested yet, allowing projection for irrigation scheduling.

In this study, new numerical scheme which was developed to determine irrigation and maximize net incomes at each irrigation interval was verified through three field trials. Quantitative weather forecasts which are freely available on the internet were used as input data. This scheme was incorporated in a numerical model, WASH 2D, which simulates two-dimensional water, solute, heat movement in soil with finite difference method. Net income was assumed as a function of cumulative transpiration over the irrigation interval. By predicting transpiration rates, the irrigation depths can be optimized to maximize net income. The crop parameters used in the model include the stress response function, which estimates root water uptake using matric and osmotic potentials. Water pricing is also considered in this scheme to give farmers incentive to save water.
To evaluate the economic benefits of this scheme, we carried out three field experiments in the sand field of Arid Land Research Center, Tottori University, Japan. We compared this scheme with automated irrigation system (AIS) as it efficiently meets plant requirements by setting appropriate trigger value of soil water content or soil suction. On the other hand, the AIM requires high initial investment and fails to adjust irrigation interval to weather forecasts, especially the traditional methods. The objective of this study was to verify the new scheme to optimize irrigation depth which gives maximal net income.

In chapter one, I showed general introductory for status of water resources in the world. Rapid growth of the world population will require more water and food in the future. Agriculture sector uses more than 70% of all water withdrawals; therefore, the importance of irrigation for food production should be addressed carefully. To do so, researchers adopted a concept of irrigation scheduling which has been showed good results in irrigation management. Deficit irrigation is a practice derived from irrigation scheduling, used to maximize crop water productivity. Due to climate change which will affect the agriculture production, the merging weather forecasts in agriculture should be adopted. Nowadays, modern technologies in agriculture are widely developed. Those technologies include devices and software. Extensive practical use of models in agriculture water management has shown satisfactory results for crop production, and simulating water flow in soils. This eventually will lead to maximize net profits of farmers.

In chapter two, I presented the governing equations, sub-models and methodology of how the proposed

numerical scheme is incorporated in the numerical model, WASH 2D. I started by addressing equations of how to determine irrigation depth and thereby, maximize net income. Assumptions like as water pricing or relation between dry matter and cumulative transpiration rate were also presented. In this study, WASH 2D model was used to combine the proposed scheme. Details of this model were also presented. I also showed how to perform the routine optimizing procedure. The implementation of this scheme using WASH 2D model was also explained through a set of steps. .

In chapter three, method and results of an experiment for potato (Solanum tuberosum L.) which was carried out in 2015 to examine this scheme compared to AIS was reported. Results indicated that predicted water content agreed well with observation although some underestimation of water content due to overestimation of transpiration was observed. Proposed scheme could save water by 32%, while yield was increased by 15%, resulting in higher net income as compared to automated irrigation. Based on these results together with previous works, we can conclude that proposed scheme can at least realize similar net income to automated irrigation systems without high initial investment.

In chapter four, method and results of an experiment for sweet potato (Ipomoea batatas (L.), cv. Kintoki) which was carried out in 2016 to examine this scheme compared to AIS was reported. Results showed that Under the proposed scheme, 18% less water was applied, yield increased by 19%, and net income was increased by 25% compared with the results of the automated irrigation system. In addition, soil water content simulated by the proposed scheme was in fair agreement with observed values. Thus, it was shown that the proposed scheme may enhance net income and be a viable alternative for determining irrigation depths. In chapter five, method and results of an experiment for groundnut (Arachis hypogaea L.) which was carried out in 2017 to examine this scheme compared to AIS was reported. Results showed that proposed scheme achieved higher yield about of 19% and net income 2.18 times, compared to AIS. It required more water about of 28%, compared to AIS. Larger amount of resulted yield could cover the cost due to water price and achieve higher net income.

In chapter six, an example for determining the tolerance of groundnut to drought and salinity stresses in terms of parameters of a macroscopic root water uptake model was shown. Estimated drought stress response function indicated that groundnut is more sensitive to drought compared to canola and Jatropha. While, it was found to be more tolerant to salinity stress than canola and Jatropha. Matric potential was more determining for growing groundnut than osmotic potential in terms of root water uptake. These are needed as input data for WASH 2D model.

In chapter seven, general discussion was made out to show the benefits and drawbacks of the proposed scheme. I also illustrated some data trying to overcome such difficulties.

In chapter eight, I gave conclusions after discussing the result of the three experiments. The proposed scheme effectively considered future rainfall events that could improve irrigation management compared to AIS. This scheme would be less applicable for the clayed soil because of longer irrigation intervals and associated uncertainty of weather forecast. Even under given uncertainty of weather forecasts, the proposed scheme was effective in determining optimum irrigation depths and increasing net income.