

Modeling Irrigation Water Requirement of Mixed Crop with Coupled Smart Irrigation System and System Dynamic Model [†]

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Abstract: Water is a key component in the two biggest economic drivers of Taiwan, i.e., the semiconductor and agricultural industries. Agricultural water accounts for 70% of the total water usage of the nation. During drought situations, the allocation and utilization of agricultural water usage become an important issue where farmers pump groundwater to supply the irrigation deficit from surface water, which ultimately impacts regional groundwater levels. Thus, there is a need to find a way to address its field water consumption during droughts; one way is a smart irrigation water management system. In this study, a smart irrigation water management model coupled with a system dynamic model (VENSIM) was developed for mixed crops in Central Taiwan by reducing 50% of the planned irrigation. Results can be applied as a solution to water shortage during droughts with alternate frequent adjustment of water gates to ensure water supply to tail end users.

Keywords: VENSIM model; precision irrigation; droughts; irrigation plan; paddy field



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1. Introduction

Taiwan has been facing water stress since late 2020 due to extended droughts and changing precipitation patterns under climate change, which is a wake-up call under current scenarios to devise a water rationing policy for agriculture, semiconductor, other industry, and domestic purposes. During prolonged droughts water shortages continue to challenge authorities due to Taiwan's uneven rainfall distribution, dense population, storage capacity, and geographical characteristics. Furthermore, global climate changes continue to worsen the current shortage situation and present unprecedented challenges to Taiwan's water system [1]. The persistent lack of rainfall leads to a stoppage of allocated agricultural water and transferred to industry which created unrest conditions for farmers. In 2021, 74,000 ha area of first season rice crops was deprived of irrigation water which accounts for 24% of total planted area [2]. In 2015, 43 thousand acres of paddy field did not receive water for irrigation and the country's reservoir levels dipped below 50%. Taiwan is experiencing worst drought in 56 years and no typhoon passed to refill its reservoirs and level dropped down to 30% in 2021 [3].

There must be an alternative way to manage water supply equitability for all sectors because the severity of droughts is increasing and cutting down water demand for farming and chipmaking is not a viable solution [4]. The farmers should adopt new irrigation methods such as precision irrigation and smart irrigation gates. There should be the adaptation of a sensor-based soil moisture measurement smart system for making agricultural water usage more efficient. This study used system dynamic program VENSIM [5], to develop a smart irrigation system for water management with a 30% and 50% reduction of allocation in the study region of Central Taiwan. The study objective is to develop a smart irrigation water management model coupled with VENSIM simulation tool during drought in Central Taiwan.

2. Study Area Description

The site is located in Chang-Hua County having an area of 215 ha which is divided into five blocks (Figure 1). The mixed cropping system consists of paddy fields (70%) and upland crops (cabbage, 30%). There are five irrigation channels and six field water level monitoring stations.

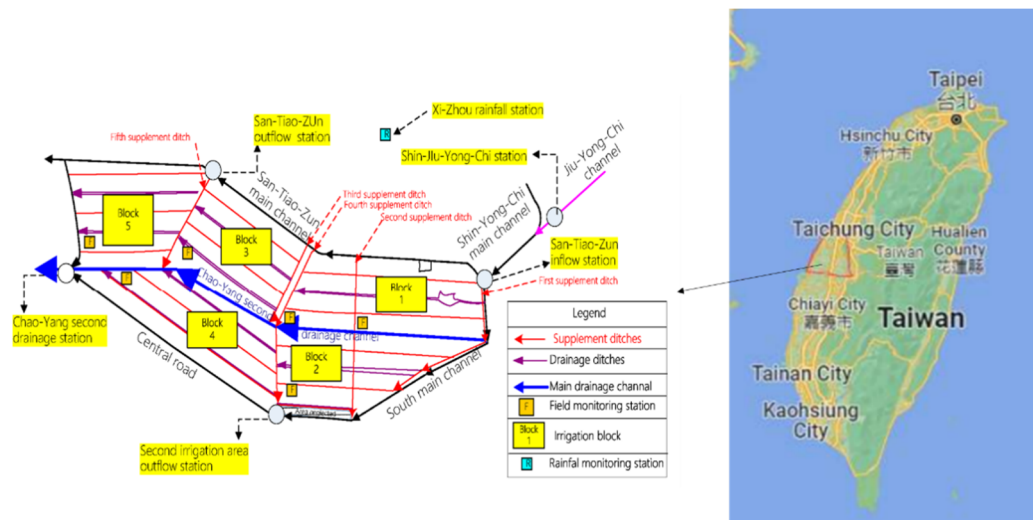


Figure 1. The layout of the experimental site.

3. Material and Methods

The water balance method is conceptualized as shown in Figure 2. The VENSIM model was formulated using mathematical governing equations. The sensors detect water levels and transfer the information to the data center at every 10 min (Figure 3). The crop water requirement model obtains data from the data center and calculates field overflow, infiltration, and evapotranspiration to estimate irrigation demand, which is then transported to the data center within a 2 h cycle.

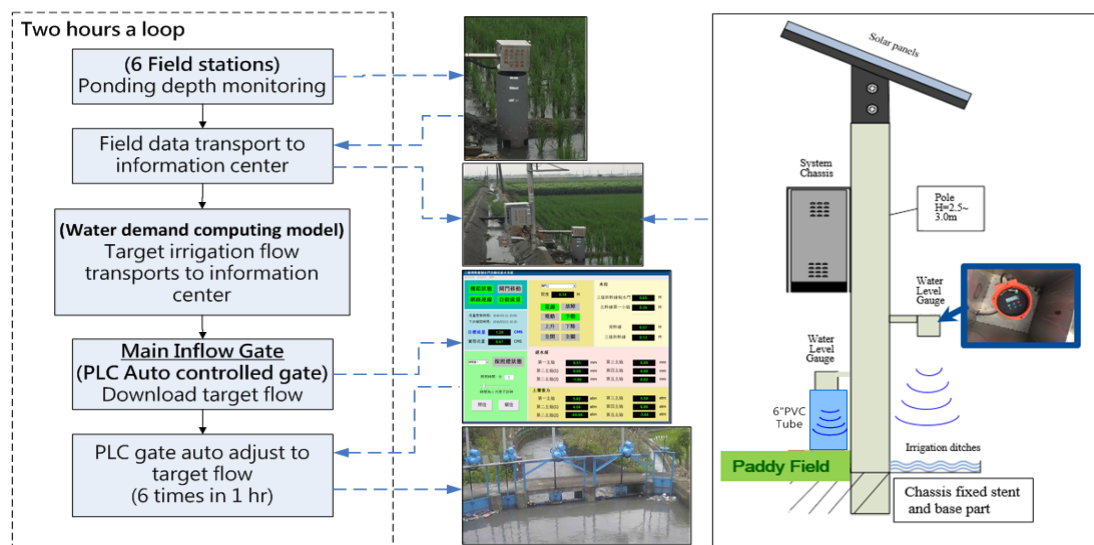


Figure 2. Smart irrigation system equipped with water level sensors and control unit [1].

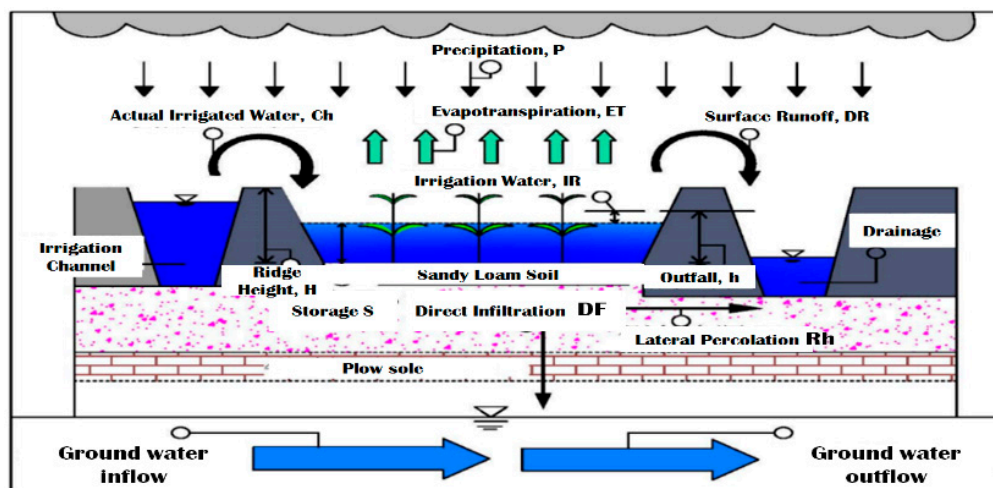


Figure 3. The conceptual model used to develop water balance approach [1].

4. Results

The model was verified with $R^2 = 0.83$ and simulation results are shown in Figure 4. During 50% reduction, the fourth block cannot have sufficient water for the target depth during survival period; however, it obtains the target depth on the 34th day tillering stage. The depth of the fifth block reached below the saturated soil moisture on the 6th day from transplanting due to the shortage of water to the 31st day. On the 21st day, the field storage becomes lower than the field capacity (FC), and the vertical percolation stops. On the 29th day, the field storage becomes much lower and reaches the wilting point (WP), stopping evapotranspiration.

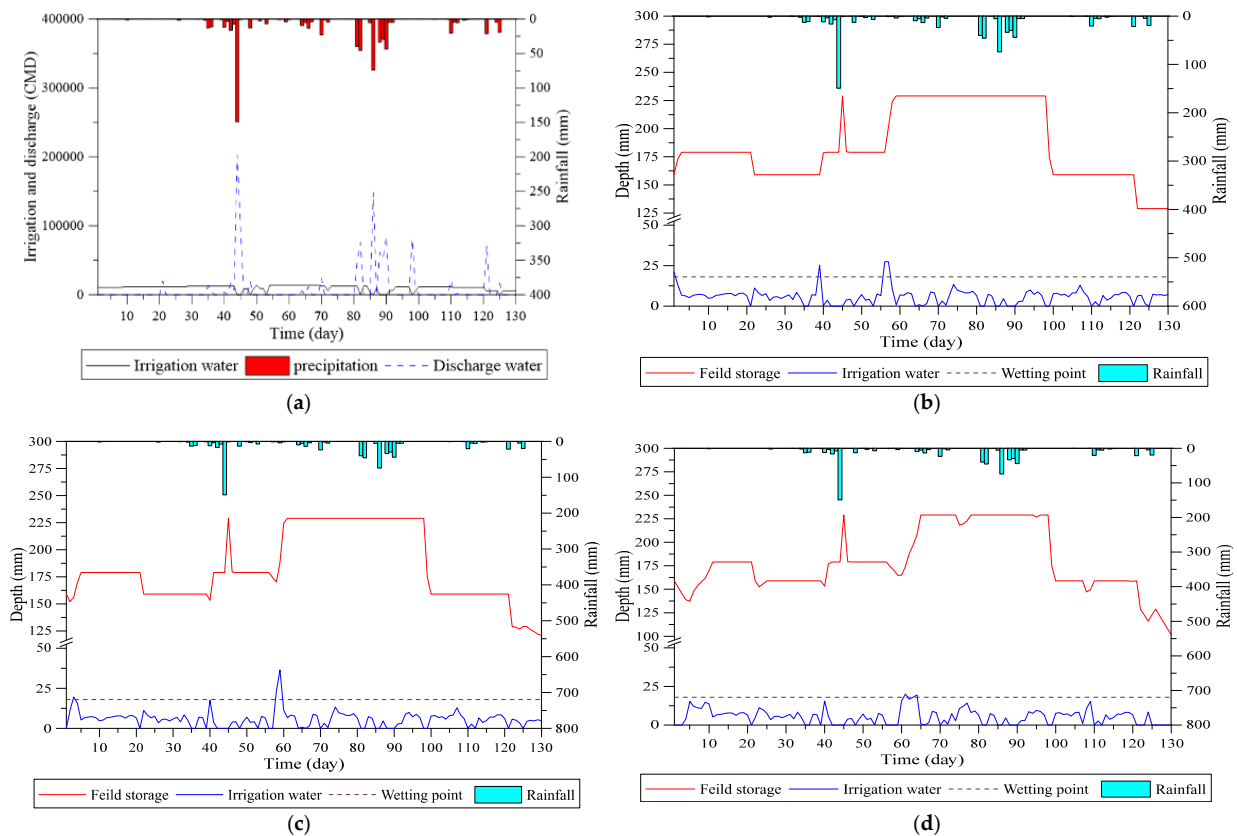


Figure 4. Cont.

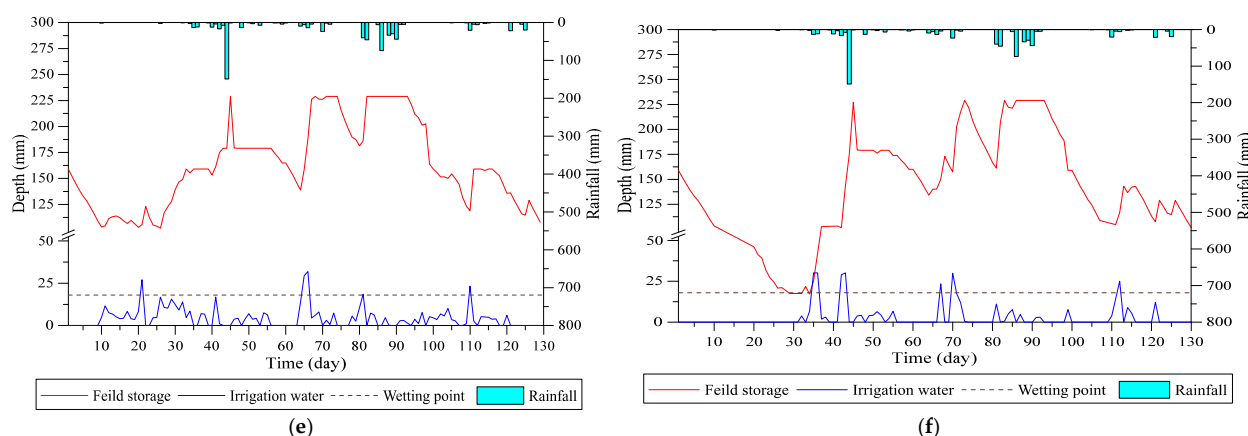


Figure 4. The simulation of a 50% drop of planned irrigation (a) and simulation of blocks 1 to 5 (b–f).

5. Conclusions

The water balance model was used to simulate an experimental site's water demand and supply to analyze water saving during drought. Stricter with drought, the scenario of a 50% reduction in irrigation water can be applied as a solution to water shortage. As a result of the study, before the 21st day, block 5 should be irrigated to avoid its field storage being lower than FC. It is suggested that when applying a 50% discount policy of provided irrigation water, every block should be irrigated in turns. When the irrigation turn belongs to the downstream area, the water gates located upstream should be adjusted recurrently to guarantee the downstream blocks can receive the allocated water rather than making irrigation water overflow in the front blocks. This model can be applied as a solution to water shortage during droughts for agricultural water management smartly by farmers.

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