最佳成本效益之雨水貯集容量設計-以桃園農業用水為例

Optimal Cost-Effective Design of Rainwater Harvesting Capacity: A Case Study on Agricultural Water Use in Taoyuan

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摘要

近年來，台灣面臨了數次嚴重的乾旱；2021 年台灣歷經了 56 年來最嚴重的乾旱，石門水庫的水位降至歷史低點蓄水量一度跌至 7%，農業生產首當其衝，稻米為台灣的主要糧食作物，生產過程尤其需要穩定水源。為了減少對水庫的依賴，雨水貯集為一種有潛力的分散式水資源管理策略。雨水貯集系統能夠在降雨量充足的時期收集並儲存雨水，在乾旱季節提供穩定的水源，減少對地下水和水庫的依賴，從而在乾旱期間維持其他用水的供應。

本研究以桃園為例，針對 2018 年資料選取有水稻種植的位置，整合網格化觀測日降雨資料與水稻分布，並在此基礎上評估這些位置在三種情境下的雨水貯集效用:(1)種植一期水稻及其他時間(2)種植二期水稻及其他時間(3)種植一期和二期水稻及其他時間。如下圖(1)所示，種植一期水稻時間為 I1，種植二期水稻時間為 I2，其餘三個時間段分別為沒有種植一期水稻的時間、沒有種植二期水稻的時間和沒有種植一期及二期水稻的時間。計算三種用水需求:一期每日用水需求(4.35 m^3)、二期水稻的每日用水需求(3.89 m^3) 和日常的每日用水需求(0.263m^3)。以三種農舍屋頂面積（200、400 和 600 m^2）作為集水區域，再以雨水桶儲存雨水；計算供水的體積可靠度、時間可靠度、滿足天數、節水量與成本等指標以評

估裝設雨水貯集的可行性。

以集水面積 600 m^2為例，可以發現不論是一期或二期水稻；隨著雨水桶容量的增加，雨水貯集的體積可靠度(圖 2)及時間可靠度(圖 3)均有所提升。在一期時間段內，正常年(乾旱年)之體積可靠度最高可達 70%(37%)，節水量 402 m^3 (212 m^3)；時間可靠度則約為 66%(30%)，滿足天數 87 天(41 天)。在二期時間段中，正常年(乾旱年)之體積可靠度可達到 54%(31%)，節水量 236 m^3 (133 m^3)；時間可靠度則約為 50%(26%)，滿足天數 56 天(29 天)。然而，由於集水面積及降雨量的限制，即使使用更大的雨水桶，也無法進一步提升供水量及可靠度。在其他時間段皆可發現，由於日常需水量較小，因此不論是體積可靠度(圖 4)以及時間可靠度(圖 5)，較小的雨水桶均能達到 80%的體積可靠度及 80%的時間可靠度。最後，運用最佳化方法找到適合的雨水桶大小以最大化成本效益。期望未來能將此方法運用至全台各縣市，用以幫助各地充分運用降雨資源。

關鍵詞：雨水貯集、雨水桶大小、最佳化方法、成本效益

ABSTRACT

In recent years, Taiwan has faced several severe droughts. In 2021, Taiwan experienced the most severe drought in over half a century. Shihmen Reservoir's water storage dropped to a historic low of 7% capacity, severely impacting agricultural production. Our main food crop, Paddy, especially requires a stable water source. To reduce dependence on reservoirs, rainwater harvesting emerges as a potential decentralized water resource management strategy. The rainwater harvesting system can collect and store rainwater during adequate rainfall, providing a stable water source during the dry season. Then, its dependence on groundwater and reservoirs is reduced, thereby maintaining the supply of other water uses during drought periods.

This study uses Taoyuan as an example, selecting locations where rice paddies were cultivated in 2018. By integrating gridded observational daily rainfall data with rice paddy locations, the effectiveness of rainwater harvesting at these sites is evaluated under three scenarios: (1) planting of the first

cropping and other periods, (2) planting of the second cropping and other periods, and (3) planting of the first and second cropping and other periods. As illustrated in Figure 1, the irrigation of the first growing season is labeled as I1, and that of the second growing season is I2. The remaining three periods correspond to times other than the first cropping, that other than the second cropping, and that other than both the first and the second cropping. Three types of water demands are calculated: daily water usage for the first rice cropping (4.35 m^3), daily water usage for the second rice cropping (3.89 m^3), and daily water usage for domestic uses (0.263 m^3). Three different rooftop areas of the farmhouses (200, 400, and 600 m^2) are considered catchments for collecting rainwater. Indicators such as volume reliability, time reliability, satisfaction in time, water savings, and costs are then calculated to evaluate the feasibility of implementing a rainwater harvesting system.

A roof area of 600 m^2 is used as an example. It can be observed that for both the first and second rice cropping, as the capacity of the rainwater tank size increases, both volume reliability (Figure 2) and time reliability (Figure 3) improve. During the first rice cropping, the volume reliability in a normal year (dry year) can reach up to 70% (37%), with water savings of 402 m^3 (212 m^3). In comparison, time reliability is approximately 66% (30%), with 87 days (41 days) of satisfaction in time. In the second season, volume reliability in a normal year (dry year) can reach 54% (31%), with water savings of 236 m^3 (133 m^3), and time reliability is about 50% (26%), with 56 days (29 days) of satisfaction in time. However, due to limitations in the roof area and rainfall, even larger rainwater tanks do not significantly improve water supply and reliability. During the other periods, the daily water demand is relatively low, allowing smaller rainwater tanks to achieve 80% volume and 80% time reliability (Figures 4 and 5). Subsequently, optimization methods were used to find the size of rain barrel to maximize cost-effectiveness. Hopefully, this method can be applied to all counties and cities in Taiwan to help fully utilize rainfall resources.

Keywords: Rainwater harvesting, Rainwater tank size, Optimization methods, Cost-effectiveness.

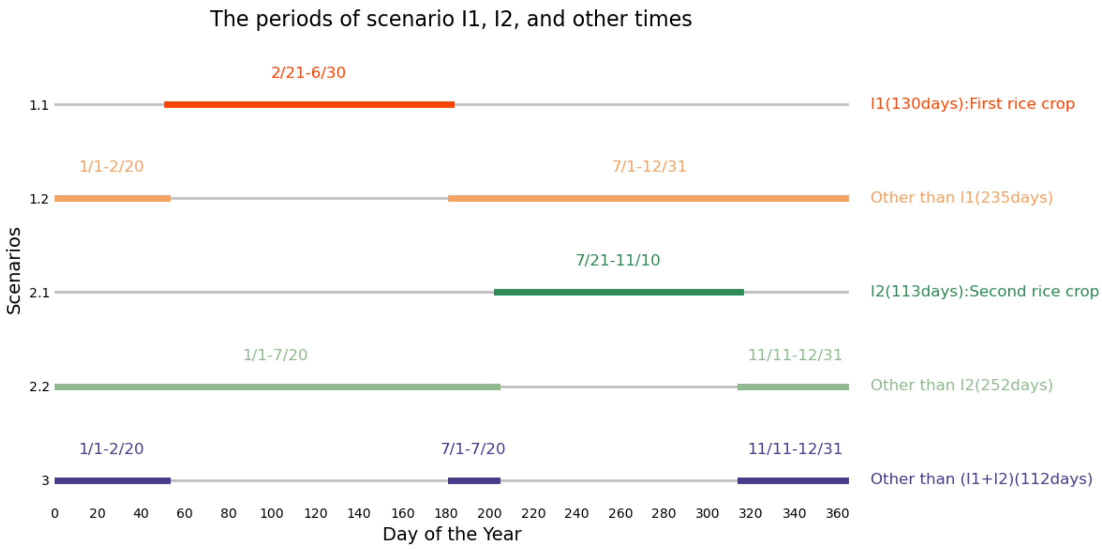

圖 1 種植一期與二期水稻時程圖

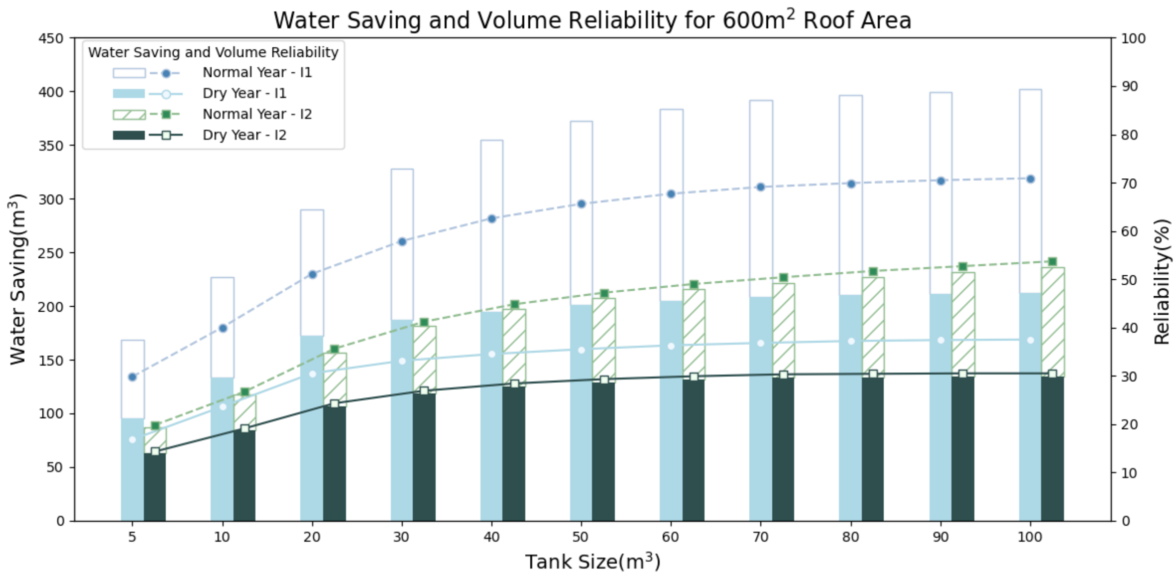

圖 2 一期與二期水稻正常年與乾旱年之節水量及體積可靠度

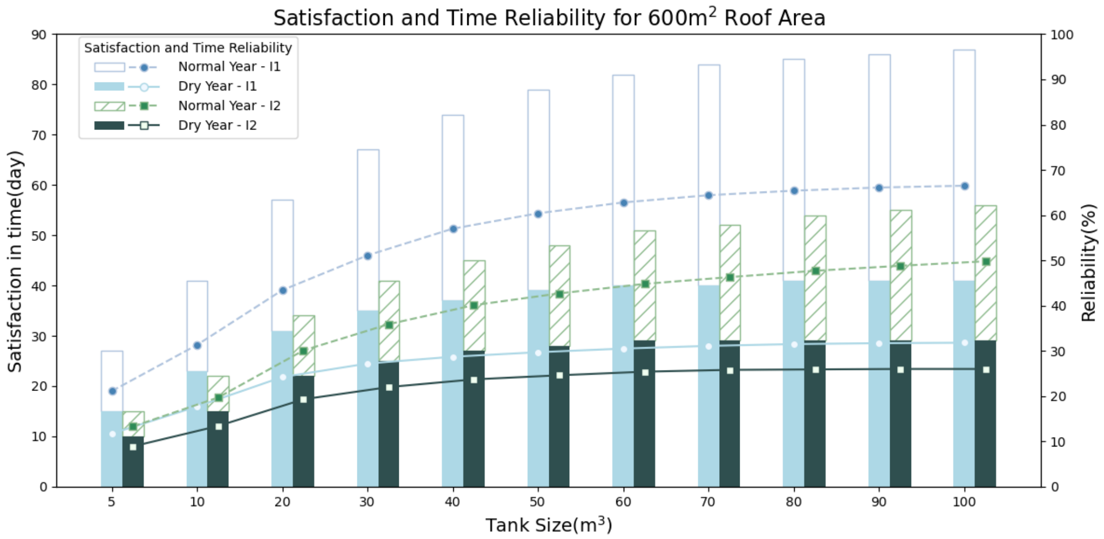

圖 3 一期與二期之正常年與乾旱年的滿足天數及時間可靠度

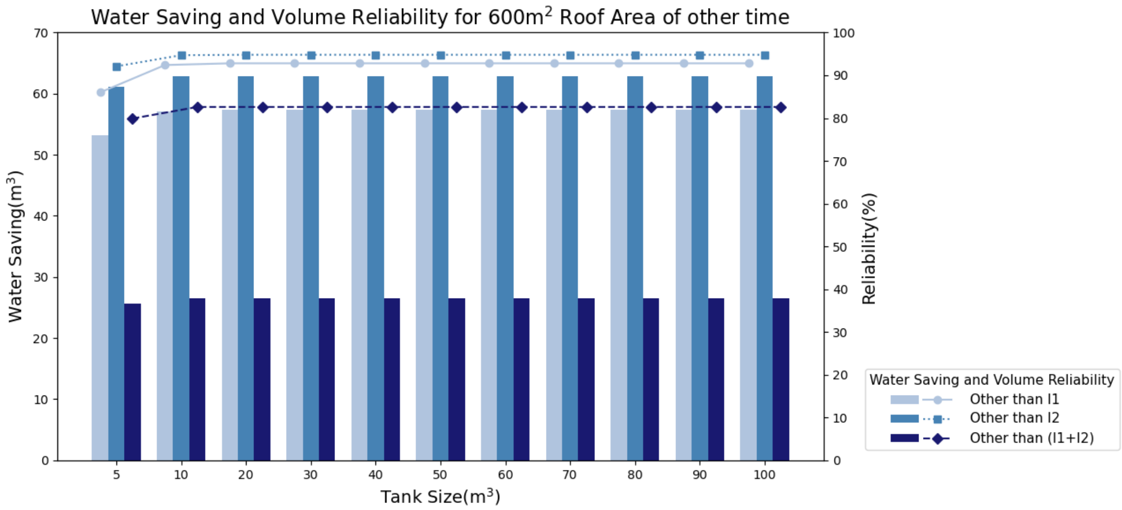

圖 4 3 種其他時間情境之節水量及體積可靠度

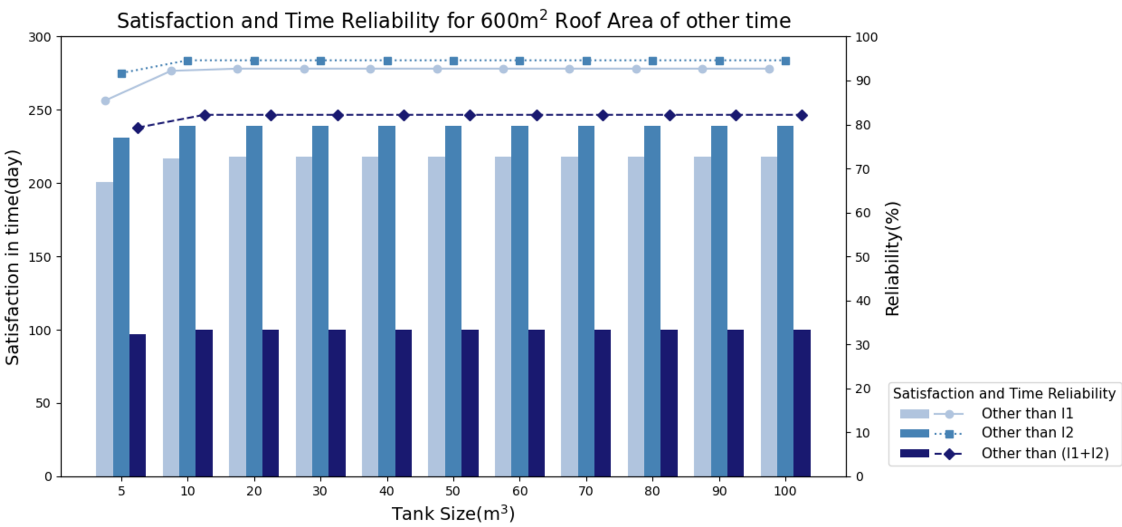

圖 5 3 種其他時間情境之滿足天數及時間可靠度