多目標最佳化下之作物配置：最大化經濟效益與作物適栽度

Crop Allocation under Multi-Objective Optimization: Maximizing Economic Benefits and Crop Suitability

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摘　要

根據2024年國家氣候變遷報告，未來受氣候變遷影響下的降雨量與流量在豐水期有增加趨勢、在枯水期則有減少趨勢，使得臺灣本土農業面臨降雨之時空特性更加不均的問題。因此在水資源之綜合管理面上，本土農業將面臨更嚴峻的挑戰。根據該報告提出之調適方針及建議，農作物生產應根據災害風險建立適地適作的農耕模式，以確保未來永續農耕活動與穩定糧食供應。因此，本研究之目的為提出一套作物配置之多目標最佳化框架，此框架將在現有農作物種植空間分布的基礎上，且僅考量作物適栽等級圖等資訊，利用多目標最佳化方法，找尋常見作物如稻米、花生在縣市尺度下之最佳種植空間分布，能滿足農業產量與經濟效益最大化。

此架構採用之最佳化方法為非支配遺傳演算法(Non-dominated Sorting Genetic Algorithm，NSGA-II)，該最佳化方法不僅具有計算速度快、廣泛適用性之優勢，且易與其他最佳化方法協作。同時，NSGA-II被廣泛應用在分配問題(Allocation problem)，例如Crop allocation (Krityakierne et al., 2024)、Land Use allocation (Shaygan et al., 2014; Song & Chen, 2018)。本研究之研究範圍為臺灣中西部，為了降低多目標最佳化模式之運算量，依據都市及區域發展統計彙編之定義，將研究範圍劃分成臺灣北部、中部與南部。研究參考作物栽種分布圖資製作網格化系統，以作為多目標最佳化模式之參數，成果如Fig.1與Fig.2所示。同時，輸入各作物之單位面積產量與農地產地價格等資料，建立最大化作物產量與收入價值兩種目標函數。基於資料稀缺，本研究將適栽圖之重疊區域視作可耕種農地區域，並限制每個網格允許栽種一種作物。最後以常用於多目標最佳化模式之指標，Hyper volume，量化此模式之表現。

本研究以多目標最佳化演算法為核心，建立一套作物多目標最佳化框架。此框架藉由輸入各作物之空間分布資訊、面積產率與單位重量收入等參數，並預期能提

供決策者了解特定作物在特定種植空間分布下可獲得之產量與經濟回饋。此框架可與現今所發展之土地利用–糧食整合模式進行合作，未來研究可加入用水需求、作物期作、碳足跡與國民飲食習慣等指標作為多目標最佳化之參考因素，使研究成果更貼近真實情況。

關鍵詞：多目標最佳化、作物種植區位、氣候變遷、適栽性

Abstract

Based on the findings presented in the 2024 National Climate Change Report, it is anticipated that the ramifications of climate change will lead to an augmentation in precipitation and streamflow during periods of increased wetness. In contrast, a reduction is foreseen during arid phases. Such developments are expected to engender more erratic spatial and temporal rainfall distributions within Taiwan, thereby presenting substantial challenges to local agricultural practices in integrated water resource management. By the adaptation strategies and recommendations delineated in the report, agrarian production should implement farming frameworks that are meticulously customized to specific locales predicated on disaster risk assessments, to ensure the sustainability of agricultural practices and the stability of food supplies in the foreseeable future. Consequently, the primary aim of this investigation is to propose a multi-objective optimization framework for the allocation of crops. This framework, which is predicated on the extant spatial distribution of crops and takes into account factors such as suitability maps, employs multi-objective optimization methodologies to ascertain the optimal spatial arrangement for prevalent crops, including rice and peanuts, at the county level, thereby maximizing agricultural output and economic advantages.

The optimization methodology employed in this framework is the Non-dominated Sorting Genetic Algorithm II (NSGA-II), recognized for its rapid computational efficiency, extensive applicability, and compatibility with other optimization techniques. NSGA-II has been extensively utilized in allocation-related challenges, including crop allocation (Krityakierne et al., 2024) and land use allocation (Shaygan et al., 2014; Song & Chen, 2018). The geographical focus of the study encompasses the central and western segments of Taiwan. To mitigate the computational burden associated with the multi-objective optimization model, the study area has been segmented into northern, central, and southern Taiwan, adhering to the classifications established in the Urban and Regional Development Statistics Compilation. A grid-based system has been devised, utilizing crop distribution maps as input for the multi-objective optimization model, with outcomes depicted in the accompanying figures. Furthermore, data on per-unit area crop yields and agricultural land prices are integrated to formulate two objective functions: the maximization of crop yield and the maximization of income value. Given the constraints posed by limited data, the areas of overlap on the suitability maps are treated as arable land, with the stipulation that only a single crop may be

cultivated within each grid cell. The efficacy of the model is assessed utilizing the hypervolume indicator, a standard metric within multi-objective optimization frameworks.

This research establishes a multi-objective optimization framework for crop allocation, focusing on a multi-objective optimization algorithm. By incorporating parameters such as the spatial distribution of crops, yield per unit area, and income per unit weight, the framework is anticipated to furnish decision-makers with valuable insights into the prospective yield and economic returns of particular crops within specified spatial distributions. This framework possesses the capacity to integrate with existing land use and food integration models. Subsequent research endeavors could expand the model to include additional indicators such as water demand, crop cycles, carbon footprint, and national dietary preferences, thereby yielding results that are more congruent with practical scenarios.

Keywords : Multi-objective optimization，Climate change impacts， Crop Suitability

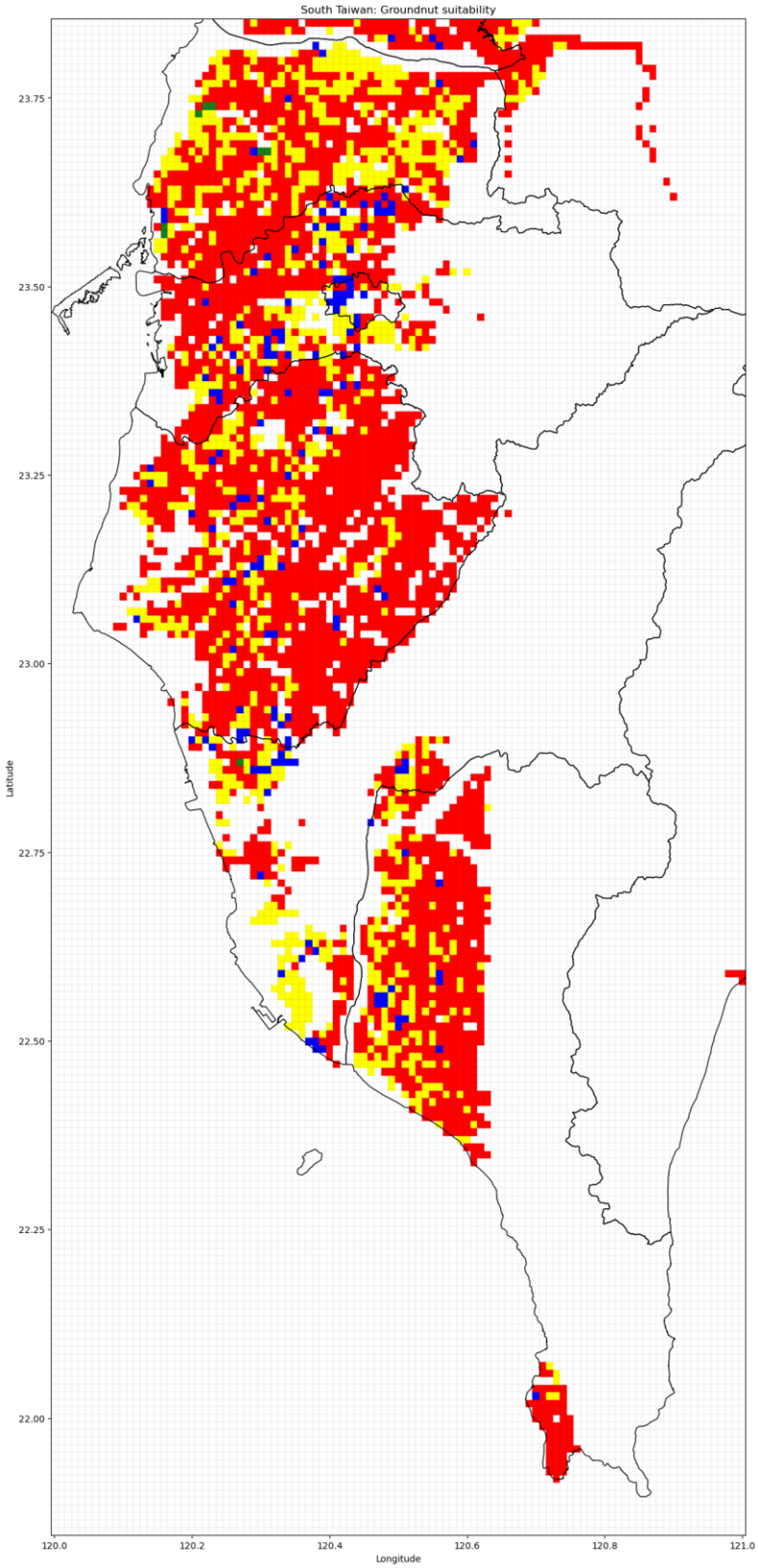

Fig. 1, 南部地區之落花生適栽分布網格

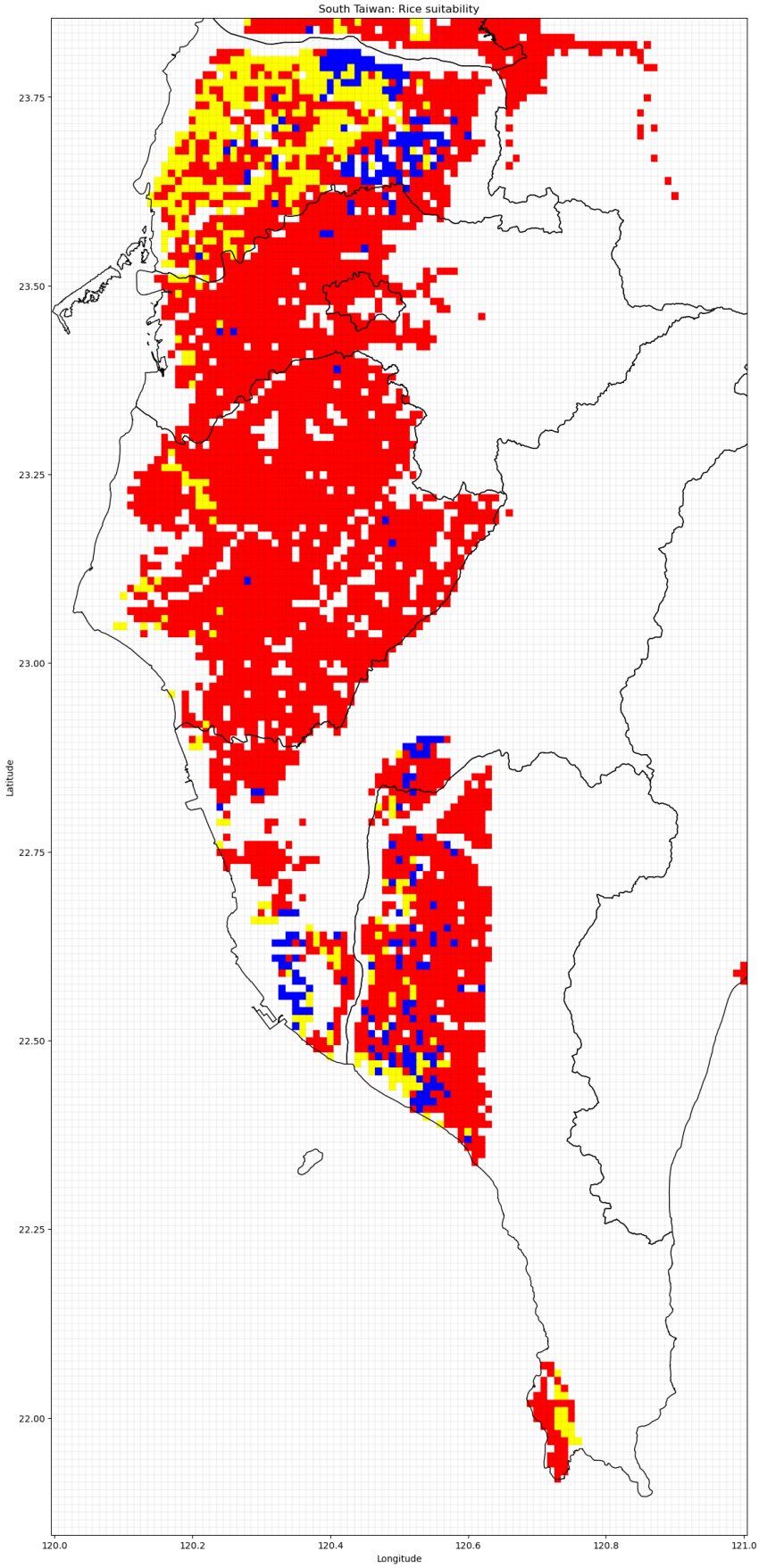

Fig. 2, 南部地區之稻米適栽分布網格