氣候變遷與土地利用對農業生態系服務之影響

Impacts of climate change and land use on agricultural ecosystem services

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摘　要

氣候變遷與人為干預將影響農業環境與耕作型態改變，進而影響營養鹽循環分布，並伴隨其他水分調節、土壤生成、碳儲存、氣候調節等生態系統服務影響，因此準確評估農業活動對生態系統之影響有其必要，故本研究以臺灣農業產值最高的雲林縣為研究區域，蒐集地表高程、土地利用/覆蓋、土壤類型、氣象等相關資料，建立 1995 年及 2016 年之土地利用/覆蓋型態下年產水量及營養鹽傳輸等之生態系服務 InVEST 模型，以量化年產水量及營養鹽傳輸，評估氣候變遷與土地利用/覆蓋變化對雲林農業地區水環境與營養鹽循環之生態系服務影響。研究結果顯示，1995 年與 2016 年間，雲林縣各土地利用/覆蓋之面積顯著變化，至 2016 年仍以農地面積(49.70%)用地最多，其中又以水田及旱田為主要之利用類型，年產水量的模擬結果表明，隨著降雨量增加，流入地表及地下水體之水量增多，且森林面積增加會進一步降低蒸發散量，提升土壤入滲及蓄水之能力，減少逕流與侵蝕，因此部分地區 2016 年的年產水量高於 1995 年，此外，對營養鹽而言，在不同地區呈現不同的變化趨勢，部分地區(如濁水溪流域、崙背沿海流域)出現輸出量增加，而其他地區(如新虎尾流域、北港流域)則顯著減少，造成營養鹽輸出量差異的原因包括土地利用/覆蓋改變、農業施肥量的調整，然而，降雨強度與降雨頻率變化也會影響營養鹽輸出，較高的降雨強度會增加地表逕流，使更多的營養鹽流失，而降雨減少或極端事件強降雨可能會影響營養鹽的淋溶過程及地下水的污染程度。此結果說明，乾旱事件會增加土壤侵蝕的風險，降低土壤含水量，並影響植物蒸發散量，減少調節服務，然而極端降雨則可能損害支持服務與食物供應服務，將對農業生產造成干擾，因此準確的評估氣候變遷與土地利用變化對生態服務系統的影響至關重要，有助於制定更為可持續的農業管理政策，以促進生態系統服務的永續利用。

關鍵詞：地下水營養鹽傳輸，氣候變遷，土地利用，生態系服務評估模型

Abstract

Climate change and human activities are altering agricultural environments and farming practices, profoundly impacting ecosystem services such as nutrient cycling, water regulation, soil formation, carbon storage, and climate regulation. Assessing the effects of agricultural activities on ecosystems is therefore essential for sustainable management. This study investigates these dynamics in Yunlin County, Taiwan's highest agricultural production region, by integrating datasets on topography, land use/land cover (LULC), soil types, and meteorological variables. Using the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model, annual water yield and nutrient transport under 1995 and 2016 LULC scenarios are quantified to evaluate the impacts of climate change and land use on water resources and nutrient cycles. According to the model evaluation, significant LULC changes between 1995 and 2016, with agricultural land (49.70%) remaining the dominant land usage, including paddy and rain-fed fields. Increased rainfall enhanced surface and groundwater recharge, while expanded forest areas reduced evapotranspiration, improved soil infiltration and water retention, and mitigated runoff and erosion. Consequently, some regions showed increased annual water yield in 2016 compared to 1995.Nutrient export exhibited spatial variability; some areas (e.g., Zhuoshui River Basin, Lunbei Coastal Basin) experienced increases, whereas others (e.g., Xinhuwei Basin, Beigang Basin) showed declines. These differences were attributed to land use changes, adjustments in fertilizer application, and climate variability. Higher rainfall intensity amplified surface runoff and nutrient loss, while reduced rainfall or extreme precipitation events affected nutrient leaching and groundwater contamination. Drought events heightened soil erosion risks, decreased soil moisture, and disrupted evapotranspiration, reducing regulatory services. Conversely, extreme rainfall posed threats to supporting and provisioning services, impairing agricultural productivity. These findings underscore the critical importance of assessing climate and land use changes to inform sustainable agricultural management policies and ensure the long-term viability of ecosystem services.

Keywords: Groundwater Nutrient，Climate change，Land Use，Invest model