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Drainage management strategies to sustain shallow freshwater resources for crop growth in saline coastal polders

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Coastal low-lying agricultural areas are threatened by groundwater salinisation due to saline groundwater upconing and seawater intrusion, which can be amplified by climate change-driven sea-level rise and drainage practices. In Dutch coastal polders, such as those on the island of Texel, rainfall is the only source of freshwater for agriculture, forming shallow rainwater lenses that support crop growth. Under conventional freely discharging drainage systems, rainfall-derived freshwater is rapidly removed, reducing freshwater retention in the shallow subsurface and enhancing saline upconing. As ditch water is often brackish and alternative freshwater sources are unavailable, thinning or loss of rainwater lenses poses a serious risk of root-zone salinisation and freshwater stress for crops.

Level-controlled drainage and subsurface irrigation are promising approaches to address these challenges. In this work, we use numerical modelling to evaluate how level-controlled drainage influences freshwater availability for crop growth in comparison to conventional drainage. Level-controlled drainage systems are designed to retain excess rainfall during autumn and winter by limiting outflow, thereby enhancing freshwater storage in the shallow subsurface, while still allowing controlled discharge of surplus water to drainage ditches. During spring and summer, the system can be actively managed to use for subsurface irrigation, providing supplemental water to crops using an external water supply.

The level-controlled drainage concept with subsurface irrigation is evaluated within the framework of the AGRICOAST project, which aims to enhance freshwater availability and promote efficient water use in saline-prone coastal regions. While previous numerical studies primarily focused on saturated flow conditions, this study advances current understanding by explicitly accounting for variably saturated, density-driven groundwater flow and solute transport processes relevant to root-zone conditions. We simulate a hypothetical representative case for the island of Texel, exploring system performance under a range of hydrogeological settings, climatic conditions, and drainage configurations. Crop growth parameters are incorporated to better represent seasonal water demands and root-zone dynamics. Through scenario analysis, we assess the impacts of weather variability and salinity dynamics on freshwater availability and root-zone salinity, and evaluate the effectiveness of level-controlled drainage in mitigating salinization risks. The results demonstrate the potential of level-controlled drainage as a sustainable water management strategy to support freshwater availability for coastal agriculture under changing environmental

conditions.