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Analysis of Soil Moisture and Nutrient Dynamics for Different Crop using HYDRUS 1D model: A Review

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ABSTRACT

The HYDRUS 1D model, developed by the USDA Salinity Laboratory, is extensively used for studying solute transport and water movement in soil. It simulates one-dimensional water, heat, and multiple solutes in variably saturated media, allowing for comprehensive analysis of soil water dynamics. This study summarizes the input data requirements, calibration process, and results obtained from various studies utilizing the HYDRUS-1D model in agricultural contexts. Key findings include its effectiveness in simulating infiltration rates, moisture and nutrient dynamics in cereal and fibre crops, groundwater recharge, and salt leaching under different irrigation regimes and climatic conditions. The model's versatility and accuracy in capturing complex interactions within the soil-plant-water system make it a valuable tool for optimizing agricultural water management and mitigating environmental impacts. Despite its efficacy, challenges such as model validation and uncertainty assessment persist, highlighting the need for ongoing research and refinement. Overall, the HYDRUS-1D model plays a crucial role in advancing the understanding of soil hydrology and supporting sustainable agricultural practices.

Keywords: HYDRUS 1D, Solute transport, Simulation, Moisture and Nutrient dynamics, Model calibration and validation

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INTRODUCTION

The HYDRUS 1D model, developed by the USDA Salinity Laboratory, is widely utilized for studying solute transport, particularly the leaching of accumulated salt and water movement in soil. This software package, known as HYDRUS-1D, is extensively employed to simulate one-dimensional water, heat, and multiple solutes in variably saturated media (Simunek *et al.* 2008). It is capable of analysing soil water movement in one direction (upward or downward) under both rainfed and irrigated conditions, with soil water dynamics represented by Richard's equation.Soil salinity measurements taken before sowing and after harvesting crops often fail to accurately capture the vertical movement of salts in the soil profile during the crop growing season. To achieve more precise measurements of soil salinity within the soil profile, researchers have turned to the HYDRUS-1D model (Liu *et al.* 2016).

Input data requirement

To conduct simulations using HYDRUS-1D, several essential input parameters and conditions are required. These include soil hydraulic properties, which define soil water retention curves, hydraulic conductivity functions, and potentially soil temperature functions.The lower boundary of the soil profile was established at a fixed depth, typically corresponding to the maximum rooting depth of the crop (1 m, 2 m, and 3 m). However, boundary conditions at the top were determined by factors such as evaporation and precipitation. Potential evapotranspiration (PET) was computed using the Penman-Monteith equation, utilizing daily weather data such as solar radiation, air temperature, humidity, and wind speed.Moreover, crop characteristics like minimum crop resistance, surface albedo, and crop height were taken into account in the model. Potential evaporation and transpiration were estimated following the Food and Agricultural Foundation-56 approach and fine-tuned with measured leaf area index data.

The calibration of the HYDRUS-1D model relied on measured volumetric water content and soil water electrical conductivity (EC) data obtained throughout the crop growing season. Metrics such as the root mean square error (RMSE) and correlation coefficient (r) between observed and simulated results were utilized to assess the modelling performance. Following calibration, the HYDRUS-1D model was deemed appropriate for simulating soil salinity variations within the study area. Additionally, the HYDRUS-1D model computes water uptake rates as a function of soil water pressure head, providing a comprehensive understanding of water dynamics within the soil profile.

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RESULTS AND DISCUSSION

The HYDRUS-1D model has demonstrated its capability to adequately describe infiltration rates, particularly through the use of the modified Green-Ampt model. This model has been extensively utilized in simulating water movement and solute transport in various soil types, including wettable soils. However, its applicability to the infiltration of water-repellent soils (WRS) at different depths has been less explored in the literature (Yang *et al.* 2021).

HYDRUS-1D was developed by the United States Department of Agriculture (USDA) Salinity Laboratory. It has found widespread application in studying various soil processes, including the leaching of accumulated salt and water movement in agricultural soils (Liu *et al*. 2016). Yurtseven *et al.*(2013) have utilized HYDRUS-1D model to analyze water flow and solute transport in soil columns of specific dimensions, under varying irrigation conditions and water qualities. They highlighted the versatility and utility of the HYDRUS-1D model in addressing diverse research questions related to soil hydrology and solute dynamics.

Water and nutrient dynamics for cereal and fibre crops

In this context, Liu *et al*. (2016) applied the HYDRUS 1D model to study a winter wheat-summer maize cropping system. They calibrated model based on measured volumetric water content and soil water electrical conductivity and they found that yields significantly increased under saline water irrigation during the jointing stage, while no significant yield reductions occurred than fresh water irrigation. Likewise, Chen *et al.*(2022)investigated field water and nitrogen dynamics in paddy fields using a well-calibrated HYDRUS-1D model. They observed better accuracy in simulating NO_3^--N concentration compared to NH_4^+-N. Moreover, they found that increased rainwater storage in paddy fields led to higher deep percolation losses and increase the risk of nitrogen leaching. Gulati *et al.*(2022) applied HYDRUS-1D model to estimate potential groundwater recharge in the central Punjab region of India. They observed excessive surface runoff losses due to higher average rainfall during the growing period of transplanted and direct seeded rice (DSR). Transplanted rice observed lower percolation losses than direct seeded rice due to puddling. Li *et al.*(2014)assessed water flow and nutrient losses in DSR fields across varied conditions. Chen *et al.*(2022) investigated field water and nitrogen dynamics in paddy fields located in Jiangsu Province, China. Conversely, Mo'allim*et al.*(2018) analysed water balance components in rice fields under conventional irrigation system. Similarly, Sepaskhah and Tafteh(2012)simulated water and nitrate leaching in rapeseed and maize fields under varying nitrogen rates and irrigation. Iqbal *et al.*(2020)examined into soil-water dynamics in sweet corn production in tropical rainfed conditions. Patle*et al.*(2018) modelled soil moisture dynamics in irrigated sugarcane crops. Er-Raki *et al.*(2021)assessed the potential of HYDRUS-1D in estimating soil moisture and evapotranspiration in winter wheat fields under varying water management scenarios in semi-arid region of Morocco. Moreover, Moghbel*et al.*(2022) simulated soil salinity in corn root zones under a linear move sprinkler irrigation system.

Overall, these studies demonstrate the versatility and effectiveness of HYDRUS-1D in simulating various aspects of soil water dynamics, nutrient transport, and crop growth in different agricultural systems and environmental conditions. Worldwide, various studies were conducted to estimate components of water and nutrient dynamics under field conditions are presented in Table 1.

Table 1: Water and nutrient dynamics in cereal and fibre crops

Parameters	Crop	Location/Site	References
Soil salt accumulation and grain yield	Winter wheat-summer maize	North China	Liu *et al*. (2016)
Field water and N dynamics	Paddy	Jiangsu Province, China	Chen *et al.* (2022)
Groundwater recharge	Paddy	Central Punjab	Gulati *et al.* (2022)
Water flow and water losses	Paddy	Taiho Lake Basin, East China	Li *et al.* (2014)
Nitrogen (solute) transport	Paddy	Tanjung Karang Rice Irrigation Scheme, Sawah Sempadan,	Mo'allim *et al.* (2018)
Ground water flow simulation	Paddy	Tedori River alluvial fan, Japan.	Iwasaki *et al.* (2014)
Watermovement through soil profile	Paddy	Kushtia, Bangladesh	Roy *et al*. (2021)
Soil water percolation and water balance	Paddy	Jingmen City, China	Xu *et al*. (2017)
Groundwater table and water balance	Cotton	Xinjiang, China	Han *et al.* (2015)
Groundwater table and Solute (Atrazine) concentration	Agricultural lands	Zwischenscholle Aquifer, Germany	Beegum *et al.* (2020)
Solute (salinity) transport	Corn	Garden City, Kansas	Moghbel *et al*. (2022)
Soil water dynamics	Sweet corn	Serdang, Malaysia	Iqbal *et al.* (2020)
Water balance components	Winter wheat	Marrakech city, Morocco	Er-Raki *et al.* (2020)
Water and solute (salt) transport	Wheat	North China plain	Li *et al.* (2021)
Water movement	Wheat	RamotYssakhar, northern Israel	Miller *et al.* (2019)
Water movement scenarios	Winter wheat	Fergana Valley, Central Asia	Karimov *et al.* (2018)
Groundwater contribution to the Root Zone	Wheat	Bangbu City, Anhui Province, china	Zhu *et al.* (2018)
Soil water dynamics	Sugarcane	Karnal district, Haryana, India	Patle *et al*. (2018)

Water and nutrient dynamics in horticultural crops

In this context, Ventrella **et al.**(2019)optimized a simulation framework to describe soil water fluxes in horticultural cropping systems, particularly in drip-irrigated watermelon cultivation. Ghazouani **et al.**(2016)applied HYDRUS model to determine optimal drip lateral depth for eggplant crops under localized irrigation. Autovino **et al.**(2018)assessed soil-water dynamics in olive orchards under different irrigation systems.Mokari**et al.**(2019) estimated soil-water and nitrate-nitrogen variations in flood-irrigated pecan orchards using HYDRUS-1D and highlighted the model's ability to simulate soil moisture dynamics and inform nitrogen management strategies.However, Ogundipe **et al.**(2016)assessed soil water dynamics in tomato cultivation under different irrigation regimes in Nigeria. They compared the result of the soil water balance (SWB) approach and HYDRUS 1D model. They found both methods suitable for simulating soil water dynamics in humid tropical climates, although with some discrepancies in SWC approach estimation. Globally, various studies were conducted to estimate components of water and nutrient dynamics in horticultural crops conditions are presented in Table 2.

Table 2: Water and nutrient dynamics in horticultural crops

Parameters	Crops	Locations/ sites	References
Water fluxes	Watermelon	Southern Italy	Ventrella*et al.* (2019)
Soil water dynamics	Garlicand Pepper	Lake Tana basin, North western Ethiopia	Bekele*et al.* (2018)
Soil water movement	Japanese spinach	Japan	Sao *et al.* (2021)
Heat and water movement	Soybean	Gifu Prefecture, central Japan	Kader*et al.* (2019)
Soil water and rootater/ nitrogen uptake	Pepper	China	Lu*et al.* (2016)
Water balance components	Vineyard	Bastica and Zadar, Croatia	Filipovic*et al.* (2021)
Soil water movement	Tomato	Ogbomoso, Nigeria	Ogundipe*et al.* (2016)
Water movement	Almond orchard	California, USA	Yang (2022)
Solute (nitrogen) movement	Pecan orchard	New Mexico	Mokari*et al.* (2019)
Soil water movement and soil hydraulic conductivities	Almond and Pistachio Orchards	San Joaquin Valley, California	Helalia*et al.* (2021)

CONCLUSION

Overall, various studies have highlighted the importance of considering factors such as evapotranspiration, soil texture, and water management practices in agricultural water management. The HYDRUS-1D model has been effective in simulating complex interactions in various agricultural systems, including puddled paddy fields, sugarcane cultivation, and sweet corn production under tropical rainfed conditions. Moreover, researchers have utilized the model to assess groundwater recharge, deep percolation losses, and nitrate leaching in different cropping systems, providing insights for optimizing water use efficiency and minimizing environmental impacts. Despite its effectiveness, some studies have noted discrepancies in simulating soil water dynamics under certain conditions, emphasizing the need for further model calibration and validation. Overall, the HYDRUS-1D model continues to be a valuable tool for understanding and managing soil-water-plant interactions in agricultural systems.

CONFLICT OF INTEREST

All the author both individually and collectively, affirms that they do not possess any conflicts of interest either directly or indirectly related to the research being reported in the publication.

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