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Enhancing near-surface soil water and temperature simulation through fine-scale field observations and mechanistic modelling

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Abstract: Successful crop establishment is frequently constrained by highly variable environmental conditions, including erratic rainfall, extreme temperatures, and low soil moisture. Seedling emergence involves two sensitive and sequential physiological processes: (1) seed germination at the sowing depth and (2) hypocotyl/coleoptile elongation to the soil surface. Both are strongly influenced by near-surface soil moisture and temperature. Accurately characterising or predicting these soil dynamics is crucial for optimizing sowing time and improving establishment outcomes.

However, direct measurement of near-surface soil water content remains technically challenging due to sensor limitations in resolution, sensitivity, and interference caused by the disparity in dielectric properties at the soil surface/air interface, resulting in an underestimate of soil moisture content at shallow soil depths. To address this, we employed a time domain reflectometry (TDR) sensor array (Sheng et al., 2017) installed at 1 cm intervals from 0.5 to 8.5 cm depth to capture high-resolution soil moisture data, complemented by soil temperature measurements.

Although APSIM-SWIM3 has been validated for its ability to simulate soil water dynamics within the soil profile (Huth et al., 2012), performance of SWIM3 in capturing near-surface water and temperature gradients has not been thoroughly tested, especially the extreme variations within the seeding zone during summer fallows ahead of crop sowing.

The high-resolution dataset of soil water and temperature was collected at a monitoring site established under natural field conditions in Avondale, Western Australia, with two contrasting surface residue treatments (bare soil and a 4-t ha⁻1 wheat stubble cover) to access the influence of soil conditions on the near-surface soil microclimate. We use this high-resolution dataset to discuss/illustrate how APSIM-SWIM3 simulations can be improved to better predict near-surface soil water and temperature dynamics by accounting for sub-daily rainfall variability, evaporative demand, soil physical properties, vapour flow, and surface residue effects. We found that the use of sub-daily rainfall inputs improved the model's ability to capture increases in soil moisture at deeper depths associated with rapid infiltration of rainfall in permeable soils. Representing the extent of drying in surface soil during summer required adjustments to the vapour flow conductivity. This adjustment may relate to vapour flow driven by temperature gradients rather than the isothermal vapour flow included in SWIM3 and requires further examination. This work would highlight the potential of integrating fine-scale field observations with mechanistic modelling to improve prediction of both temporal variability and vertical gradients for soil moisture temperature in near-surface soil conditions, thus providing critical insights into the micro-environmental factors influencing seedling emergence and supporting management decisions under increasingly variable climatic conditions.

REFERENCES

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