New modelling methodology for improving crop model performance under stress conditions

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Introduction

Crop models exhibit large uncertainty in the quantification of risks imposed to food production by climate change (Asseng et al., 2013). A significant step towards reducing this uncertainty is to improve model structure (Tao et al., 2018). Here, we present a new modelling methodology for improving crop model structure based on simultaneous solution of model equations. The new technique is called SEMAC (Simultaneous Equation Modelling for Annual Crops) and is implemented into the GLAM crop model, resulting in a new model version GLAM-Parti (i.e. GLAM Partitioning). The new model has improved structure, it gives a better connection between the model processes and leads to higher internal consistency. The model skill is significantly increased when tested under different stress environments (i.e. water and ozone stress).

Materials and Methods

SEMAC develops a system of simultaneous equations which accounts for all above-ground crop growth and development processes. It uses allometric relationships to connect the masses of all plant compartments, which allows the expression of above-ground biomass as function of leaf mass. SLA and daily biomass growth are set as function of LAI. This forms a system of equations with equal unknown variables which is solved simultaneously to return the values of all unknown variables. A detailed description of SEMAC as well as its incorporation into the GLAM crop model is given in Droutsas et al., 2019. Here, SEMAC is tested for its ability to capture stress due to water and ozone in turn.

Results and Discussion

GLAM and GLAM-Parti were tested for wheat under various levels of water stress and GLAM-Parti exhibited higher skill in all experiments. The total RMSE of GLAM-Parti was reduced by 45% for grain yield in comparison with GLAM (Fig. 1A). We tested the relative contributions of the simultaneous equation system and the model improvements and found that the model which had both (i.e. GLAM-Parti) improved upon the same model with sequential solution methodology (i.e. GLAM-Partiseq). The model calibration (i.e. GLAM-Partiseq-cal) can only partially but not fully compensate for the inconsistencies of the sequential method. In addition, ozone stress was tested under CEMAC using a new parameterisation for wheat, including the acclimation mechanism under chronic exposure to the pollutant. The model successfully reproduced the observed yield reduction under variable duration of exposure to ozone (Fig 1B).

Conclusion

SEMAC is a new modelling technique for the simulation of crop growth and development. Applying the methodology into a crop model overcomes structural limitations. The step-by-step way of solving the model equations is replaced by simultaneous solution. This provides higher internal model consistency and increases the model skill. In this study, GLAM-Parti improved upon GLAM in the simulation of wheat growth and yield in all levels of water stress. The model was also successfully tested for the effect of ozone on wheat yield. SEMAC could be applied in other crop models to see if similar improvements in skill result.

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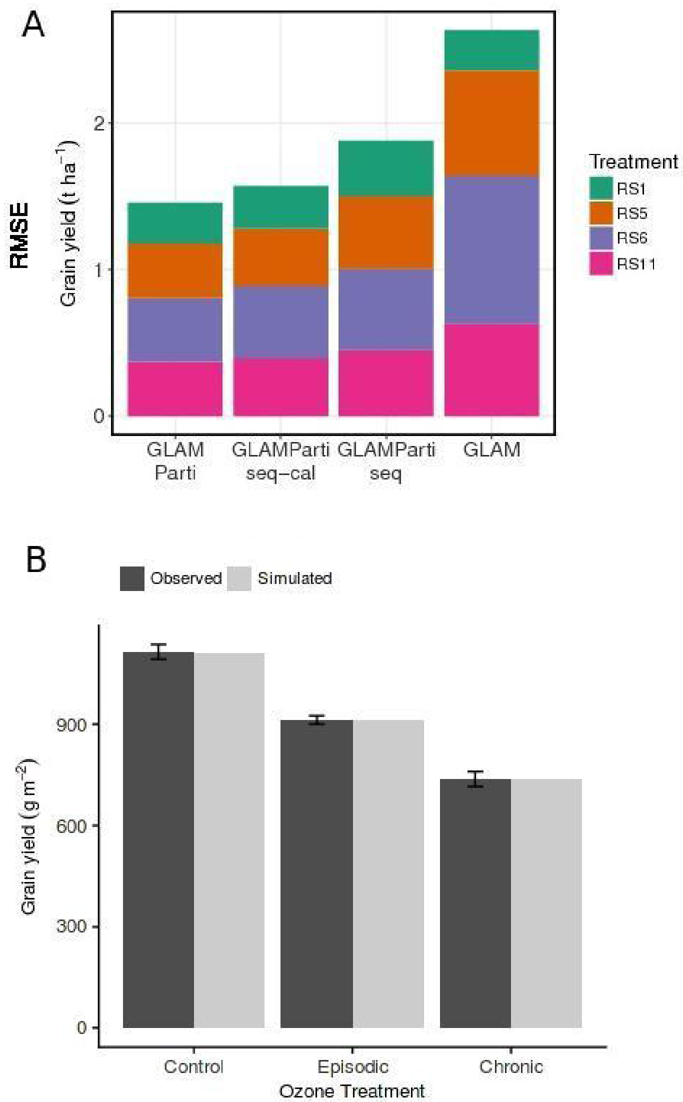

Fig. 1. A) Root mean square error (RMSE) between modelled and observed grain yield in the different water treatments: Control treatment (RS1), early drought treatment (RS5), late drought treatment (RS6), full drought treatment (RS11). Figure was extracted from Droutsas et al. 2019. B) Observed (wheat variety KWS Bittern) and simulated grain yield at harvest in Control, Chronic and Episodic O3 treatment. Error bars are standard errors of means in the observations.

Keywords: SEMAC, GLAM-Parti, Model improvement, Water stress, Ozone.

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