A DYNAMIC SIMULATION MODEL FOR SEED GERMINATION, SEEDLING ELONGATION AND EMERGENCE

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Introduction

For sustainable production in hilly terrain it is essential to estimate the effects of variable water and energy balance on arable crops (Richter et al., 2004). Crop emergence is one of the most important processes determining yields and the probability of crop failure. Here, we describe a model to simulate seed germination and emergence. Its final outputs will provide crop models with date of emergence, the number of established plants and initial LAI.

Materials and methods

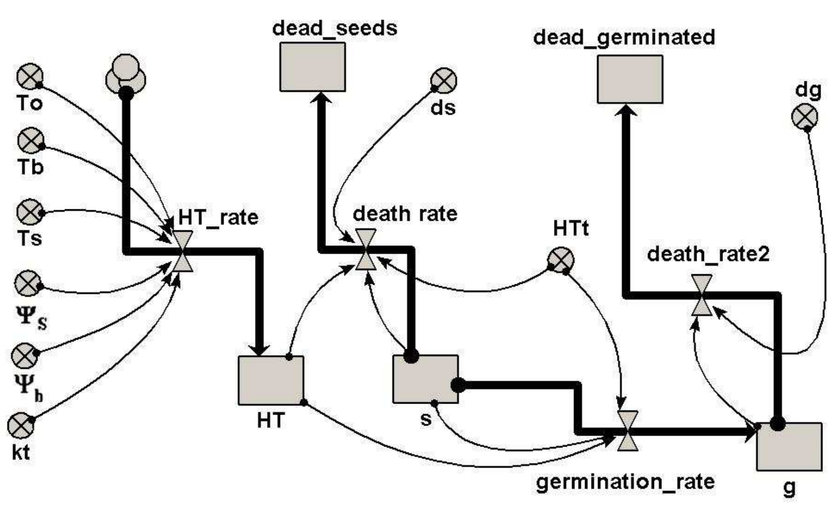
We designed and implemented two components to simulate (1) seed imbibition and germination and (2) seedling elongation and plant emergence for a generic crop. The modules run with a daily time step and are implemented in Visual Basic and SIMILE. We simulate the fate of a user-specified number of cohorts of homogeneous seeds, which can germinate, emerge and die. Model parameters can be set or generated from a known normal distribution. We carried out sensitivity analysis varying one parameter at a time and excluding the cases when emergence took more than 50 days. The average sensitivity of the response variable *f* to the change of model input *x*, calculated for several values of *x*, is defined as $\{[f(1.1x) - f(0.9x)]/[[f(1.1x) + f(0.9x)]/2]\}/0.2$.

Model description

Imbibition and germination (Figure) are driven by soil temperature and water content: using the hydrothermal time (HT), germination rates are proportional to the amount by which soil temperature (T_s) and water potential (ψ_s) exceed their base values (T_b, ψ_b; Gummerson, 1986).

Rate of HT is: $HT_{rate} = (\psi_s - \psi_b) \cdot (T_s - T_b)$ if $T_s \leq T_o$

$HT_{rate} = (\psi_s - \{\psi_b + [k_t \cdot (T_s - T_o)]\}) \cdot (T_s - T_b)$ if $T_s > T_o$



Relational diagram for the germination module; s=number of viable seeds; g=number of germinated seeds; for the other symbols, see the text.

T_o is the optimal temperature, k_t=the slope of the ψ_b-T relation when $T_s>T_o$ (Alvarado and Bradford, 2002); ψ_b is constant and independent of T_s; T_b is independent of ψ_s. The two processes are completed when the accumulated hydrothermal time reaches a species-specific threshold (HT_t). We also propose two empirical death rates, one for seeds (d_s), the other for seedlings (d_g).

Seedling elongation. Elongation of shoot and roots start at the end of germination and emergence is defined as when shoot length exceeds sowing depth D. Elongation rates are driven by temperature (T_s) and are controlled by soil penetration resistance (Q), seed weight (W) and seed reserves (R). The seedling may not emerge if reserves exhaust before emergence. Seed reserves are diminished by: i) dry matter allocation to radicle and shoot by way of two partitioning coefficients (R_c and S_c), which depend on thermal time accumulated after germination (TT_g; Tamet et al., 1996); ii) maintenance and iii) growth respiration (Lövenstein et al., 1995). Rate of shoot elongation corresponds to the rate of increase of shoot biomass using specific shoot length (e_s), which is related to penetration resistance (Vleeshouwers, 1997) by means of two empirical parameters c_1 and c_2. Shoot length is the integral of shoot elongation rate and is used to determine the day of emergence.

Results

Input parameters, their range, output range (duration of germination and emergence) and sensitivity of the model are reported in the table. The model is mostly sensitive to environmental variables (T_s, ψ_s, Q), management variables (D) and seed characteristics (T_b, ψ_b, HT_t, W, S_c).

Parameter or driving variable					Sensitivity		Germination day	
Symbol	Units	Default	Min	Max	Average	s.d.	par=min	par=max
ψ_b	MPa	-0.91	-1	-0.22	0.96	0.16	9	40
ψ_s	MPa	-0.03	-0.72	-0.01	0.96	0.94	40	10
HT_t	℃ day MPa	50.92	10	80	0.76	0.38	3	16
T_s	℃	10	6	20	1.18	0.35	21	5
							Emergence day	
c_1	$g\ cm^{-1}$	0.00041	0.0001	0.001	0.19	0.14	17	23
c_2	$g\ cm^{-1}\ MPa^{-1}$	0.00162	0.001	0.002	0.34	0.11	16	21
R_c	$g\ g^{-1}\ ℃^{-1}\ d^{-1}$	0.0024	0.0012	0.0036	0	0	19	19
W	g	0.04	0.03	0.05	0.49	0.19	22	17
S_c	$g\ g^{-1}\ ℃^{-1}\ d^{-1}$	0.0017	0.0009	0.0025	0.49	0.16	28	16
Q	MPa	0.7	0.4	1.8	0.45	0.13	16	30
D	cm	3	1	6	0.51	0.13	13	29
T_b	℃	3	0	7	0.79	0.83	13	43
T_s	℃	10	6	20	1.44	0.54	43	9

Conclusions

The model performs well in terms of output range and sensitivity to major inputs. The input requirement is not too large. Experimental data were collated to calibrate the model parameters and validate on independent data sets during the next project phase.

References

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