Herbicide transport in freezing soil

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Soil freezing

1. inhibits soil temperature changes
2. decreases the amount of liquid water
   ⇒ soil dries
   ⇒ capillary flow to freezing front
3. decreases soil hydraulic conductivity
4. forms ice crystals from pure water
   ⇒ chemicals in soil solution are excluded
   ⇒ high chemical concentration in the soil solution at the freezing front[a]
5. generates heaving
   ⇒ frost heave equal to the combined thickness of all ice lenses within the profile
   ⇒ may result new preferential pathways
6. First freezes the "free" water in the middle of large pores.
7. Freezing temperature depends on solute concentration.

CROPWATN-P is a new model.

- Start point: a 1-dim. model **CROPWATN**[b,c] for water, solute and heat balance.
- **Added: preferential flow**. The main difference between the preferential flow approaches of MACRO[d] and CROPWATN-P, is the driving force for mass exchange between soil micro- and macropores. In CROPWATN-P it is difference in pressure heads[e], while moisture in MACRO[d]. CROPWATN-P requires pF-curves for macropore-domain.
- **Added: simple pesticide fate equations**: application, sorption (Freundlich) and degradation (1st order kinetics, rate dependent on temperature, moisture and depth)
- **Added soil freezing description**: effects on heat balance; freezing as a drying process; hydraulic conductivity in frozen soil (K_{ice}): $K_{ice} = K_T / (1+ a \cdot I^2)$, where K_T is hydraulic conductivity in non-frozen soil, a is constant and I is the volumetric fraction of ice in soil (Motovilov's equatin).
- Currently: thermodynamic is not separated into the two flow domains; neither chemical exclusion from ice crystals nor soil heaving / generation of new preferential pathways are taken into account.

Summary

•In several separate Finnish studies, observed pesticide concentrations in soil tillage layer and in surface water have been higher in spring (during / soon after soil thawing) than before winter. This phenomenon might be explained by the effects of soil freezing on pesticide fate (see Fig.1).

•None of the current pesticide fate models have a proper soil freezing description. A new model CROPWATN-P was created in order to study the effects of soil freezing on pesticide transport. The model first version was tested against measured herbicide fate data, and against MACRO simulation results. The current version of CROPWATN-P does not take into account all relevant processes related to freezing, but model development is going on.

Frozen soil includes bands of ice lenses, dry soil, bound water (and non-frozen zones).

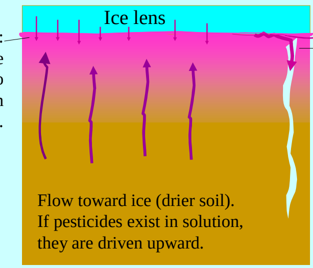


Fig. 1 The physical effects of soil freezing on pesticide fate (hypothesis)

Data used for simulations

- Field experiment was carried out in a flat plot (3500 m^2, medium-textured Glyeic Podzol), which is equipped with water collecting systems for surface runoff and tile drainage (tiles at 1-m depth).
- Ethofumesate and glufosinate-ammonium were sprayed on bare soil on 8th July; concentrations were observed in soil and in runoff waters until next May[f]. Summer after application was dry and following winter milder than usually. Soil was not frozen as deep as normally.
- Parameters: available measured data + expert judgements (e.g. pF-curves fitted using two data points / layer; the deepest known soil layer extended to the depth of 5 m). The hydrological parameters used in the two models are not exactly the same. Glufosinate-ammonium: K_F 2.5 l/mg, Freundlich exponent 0.92[g]; degradation half-life time 8.5 d[f]; Ethofumesate: K_F 8 l/mg for MACRO (and 20 for CROPWATN-P), exponent 0.92[g]; half-life time 45 d[f].

Results and conclusions

Simulation results (figures 2-16) obtained with MACRO 5.0 and CROPWATN-P did not differ remarkably from each other. Observed pesticide fate was not correctly simulated in either of the models. Simulated soil freezing effect on pesticide transport was negligible using the current version of CROPWATN-P and available dataset[f]. Model development is going on.

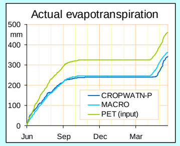
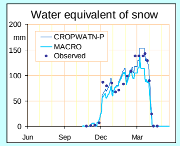


Figure 2.



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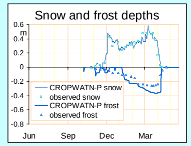

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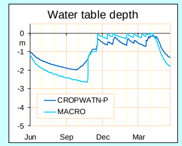
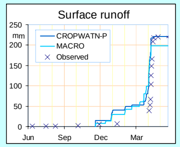


Figure 5.

Figs. 2-5. Accumulated potential (input) and actual (simulated) evapotranspiration (mm); snow water equivalent (mm), snow and frost depths (m) and water table depth (m).



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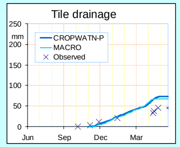

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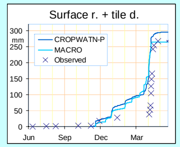
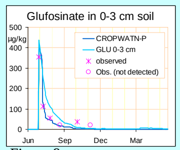


Figure 8.

The current freezing description of CROPWATN-P did not affect significantly on simulated water balance.

The parameter related to hydraulic conductivity in frozen soil (a) had no effect on tile drainage in this simulation setup.

Figs. 6-8. Simulated accumulated surface runoff (mm), tile drainage (mm) and their sum were close to measured ones, but the timing was not correct. Neither of the models were able to simulate the small runoff events during dry summer. Both models overestimated runoff and drainage volumes during winter months.



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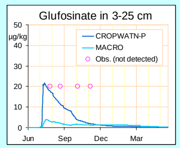
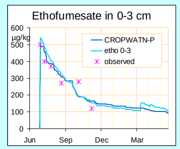


Figure 10.



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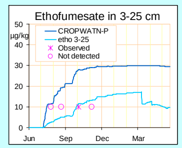


Figure 12.

Figs. 9-12. Herbicide concentrations in soil (sampling layers 0-3 cm and 3-25 cm). Only tracer concentrations were simulated for deeper soil layers (nothing detected). Measured, non-detected concentrations are set to the detection limit. The difference in simulated distribution between 0-3 cm and 3-25 cm layer may be due to different number and thickness of calculation layers.

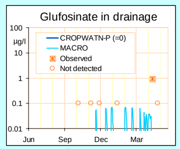
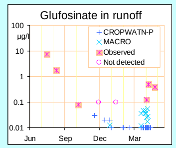


Figure 13.



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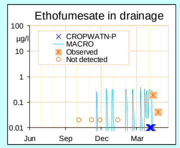

Figure 15.

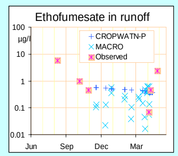

Figure 16.

Figs. 13-16 Simulated and observed herbicide concentrations in surface runoff and in tile drainage (Notice Log. Scale!). Due to incorrect timing of water flows, the simulated concentrations in runoff and in tile water mismatched. The potential runoff concentration (in MACRO: the simulated solute concentration in the liquid phase of uppermost calculation layer) mimic well the observed concentration dynamics in surface runoff during autumn. MACRO managed well in spring also. Neither of the models were able to simulate the high glufosinate-ammonium concentration peak in tile water in April. CROPWATN-P simulated correctly the timing (but underestimated the concentration) of ethofumesate in tiles.

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