Modelling competition for water between tree and crop roots in an agroforestry system

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1 Abstract

In times of climate change, many regions of the world suffer from heat waves and drought periods, which can lead to failure of crops. To a certain extent, irrigation can help to overcome these extreme events. However, in a sustainable agricultural system the water and nutrient applications should be minimized in order to avoid the waste of valuable resources.

Another method to use water more efficiently is the introduction of agroforestry systems, e.g. planting tree strips within a field. On the one hand, these tree strips reduce the evapotranspiration of the crop-soil-system due to shading and reduction of wind speed. On the other hand, temperatures tend to be higher near the trees and the tree roots may deplete available water and nutrient resources for crops.

Recently, an agroforestry sub-model has been implemented into the modular model system Expert-N to simultaneously simulate tree and crop growth. In principle, trees and crops are simulated separately at different grid points next to each other. However, the agroforestry sub-model allows for the exchange of water and matter between the different grid points to simulate mutual influences of trees and crops. Up to now the following processes are considered: shading, distribution of dead tree biomass to the crop area, and changed water distribution as tree roots grow into the crop area.

Depending on the simulated tree root length density at the crop grid points, the tree roots can uptake a certain amount of water from neighbouring grid points. If the total water demand of trees and crops cannot be fulfilled, the water uptake at the respective grid point is reduced for both, trees and crops.

Expert-N is used to simulate the plant production and the water cycle within an agroforestry system. The results comprise plant biomasses, leaf area indices, evapotranspiration, and soil water contents. To show the impact of the agroforestry sub-model on the simulation results, the differences between two simulations, which only vary in the activation of the agroforestry sub-model, are presented and discussed.

2 Simulation setup

For model testing, an agroforestry system, based on an existing field setup in Germany, has been created within the modular model system Expert-N 5.0 (Heinlein et al. 2017; Klein et al. 2017; Priesack et al. 2006).

- Simulation period: 1 April - 31 August 2016
- Included processes: soil water transport, soil heat transport, plant growth, fertilization, nitrogen transport and nitrogen transformation
- Plant models: Treedyn (Chevenet et al. 2006) simulating poplar and SPASS (Wang and Engel 2000) simulating maize
- Agroforestry model (Figure 1): light attenuation due to shading, exchange of dead biomass, root competition for soil water

In general, the agroforestry sub-model has been set up with a gridded model structure, i.e. one (or more) crop grid points are located next to a tree row. For this simulation, one crop grid point has been created, which is situated at 1.5 m from the tree strip. 25 % of the tree roots are distributed to this crop grid point.

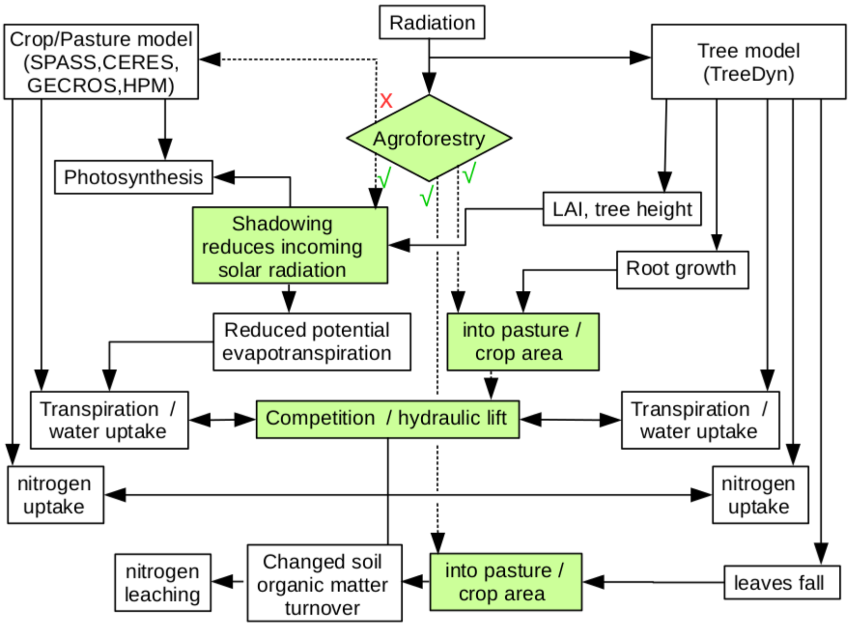


Figure 1: Flowchart of the agroforestry sub model of Expert-N 5.0

3 Graphics

All graphics show simulation results. The solid lines depict simulations with the agroforestry sub-model, the dashed lines without.

3.1 Tree

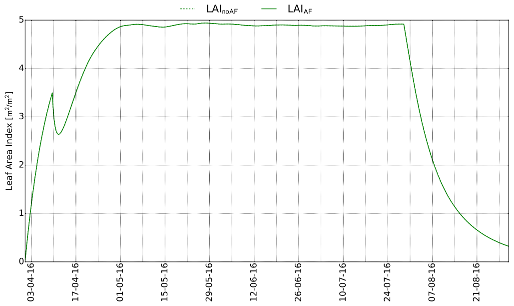


Figure 2: LAI [m^2 m^{-2}] of the tree row

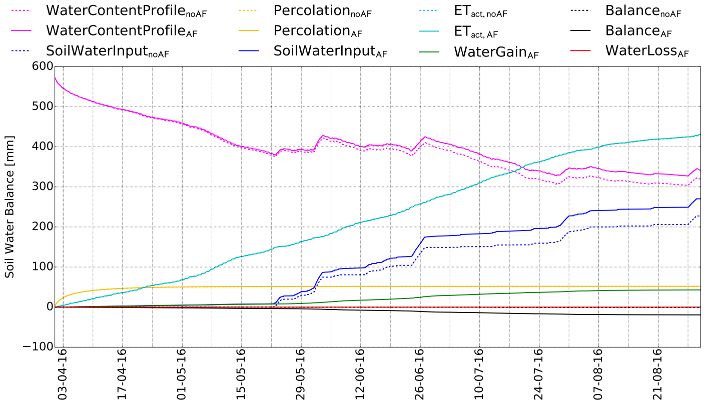


Figure 3: Components of the cumulative water balance [mm] of the tree row

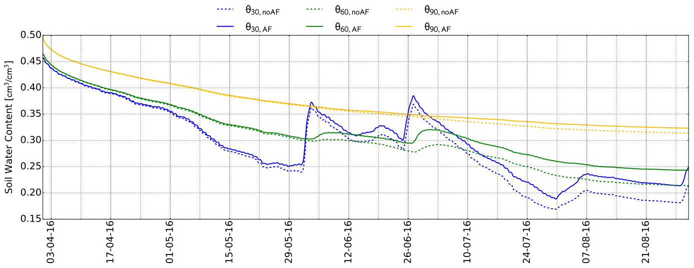


Figure 4: Soil water contents [cm^3 cm^{-3}] at 30 cm, 60 cm, and 90 cm soil depths within the tree grid point

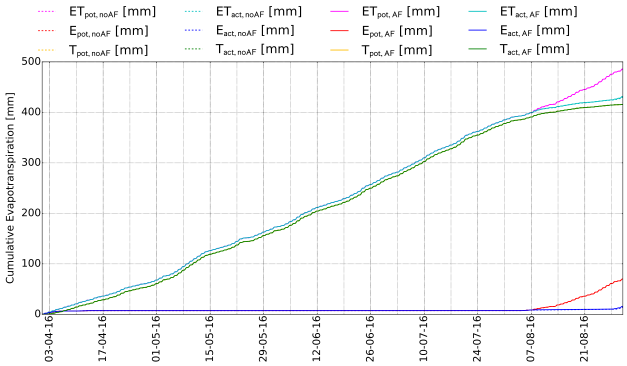
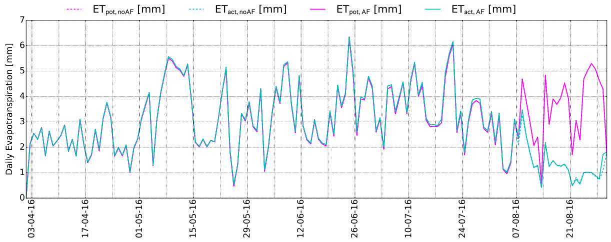
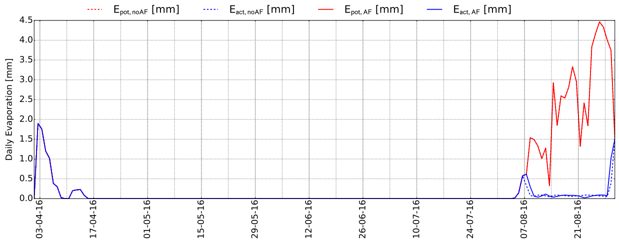


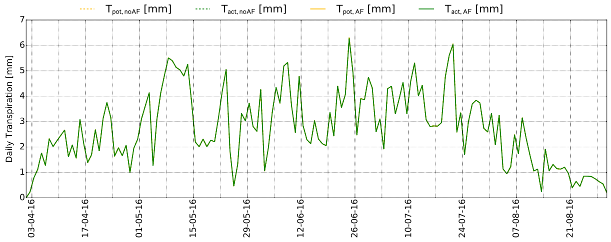
Figure 5: Cumulative Evapotranspiration [mm], Evaporation [mm] and Transpiration [mm] of the tree row



(a) Evapotranspiration



(b) Evaporation



(c) Transpiration

Figure 6: Daily Evapotranspiration [$\mathrm{mm\,d^{-1}}$], Evaporation [$\mathrm{mm\,d^{-1}}$] and Transpiration [$\mathrm{mm\,d^{-1}}$] of the tree row

3.2 Crop

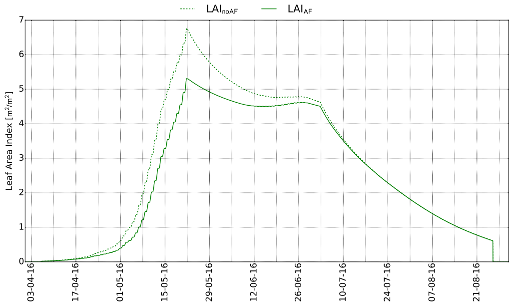


Figure 7: LAI [m^2 m^{-2}] of the crop

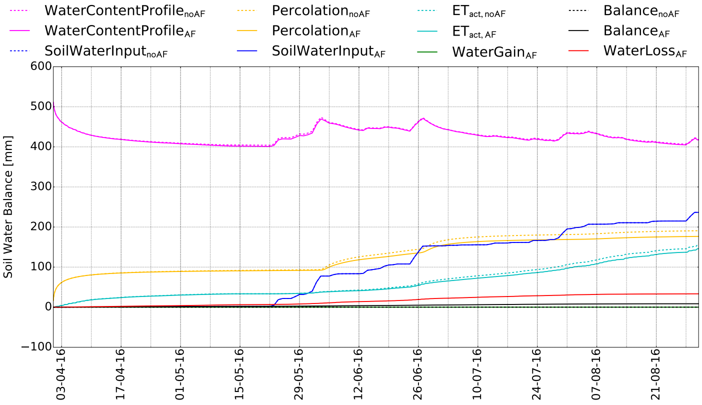


Figure 8: Components of the cumulative water balance [mm] of the crop

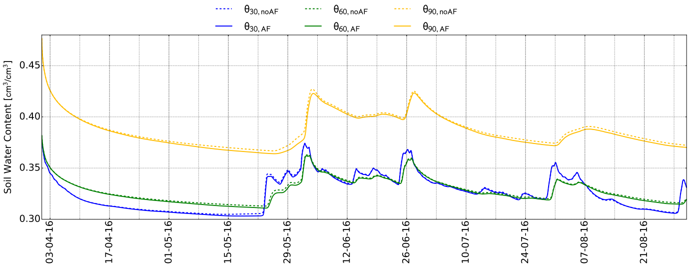


Figure 9: Soil water contents [cm^3 cm^{-3}] at 30 cm, 60 cm, and 90 cm soil depths within the crop grid point

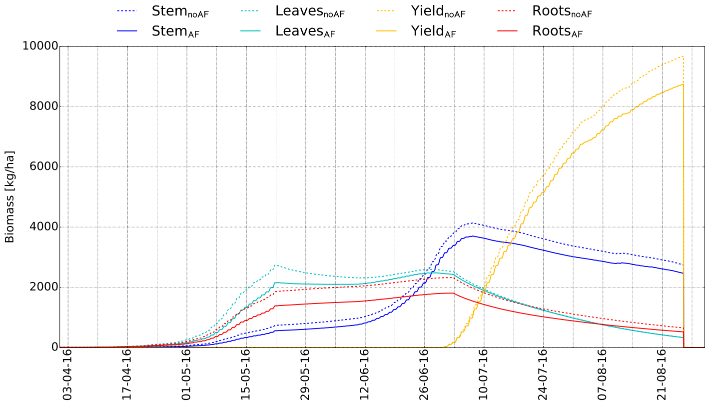
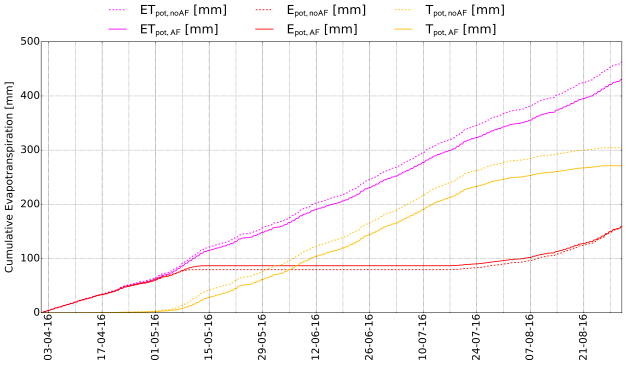
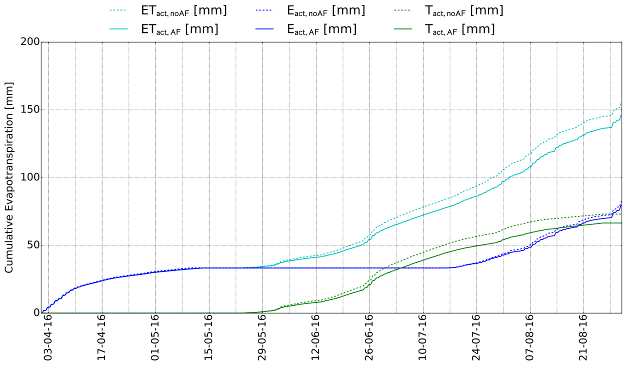


Figure 10: Biomass [kg ha^{-1}] of the crop

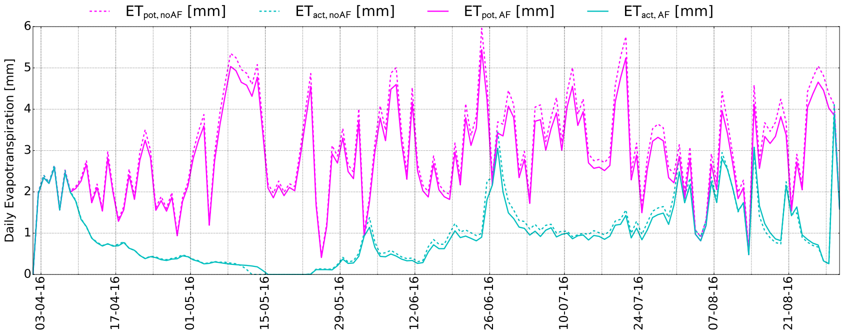


(a) Potential Evapotranspiration

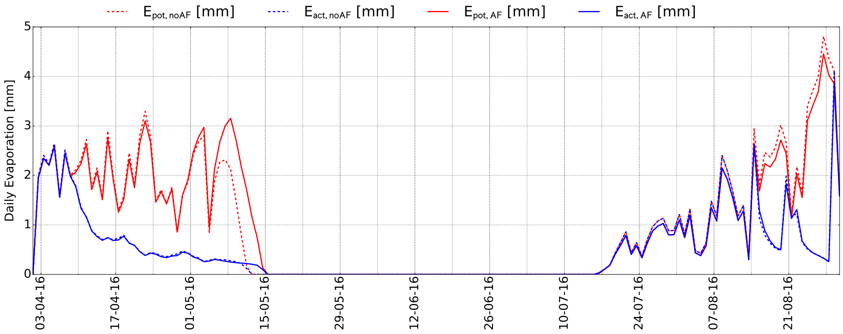


(b) Actual Evapotranspiration

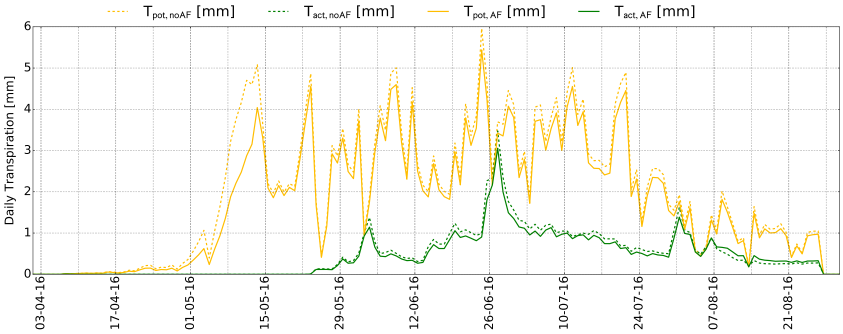
Figure 11: Cumulative Evapotranspiration [mm], Evaporation [mm] and Transpiration [mm] of the crop



(a) Evapotranspiration



(b) Evaporation



(c) Transpiration

Figure 12: Daily Evapotranspiration $[\mathrm{mm\,d^{-1}}]$, Evaporation $[\mathrm{mm\,d^{-1}}]$ and Transpiration $[\mathrm{mm\,d^{-1}}]$ of the crop

4 Comments on the graphics

The agroforestry sub-model has only little impact on the simulation of the tree growth and the tree water balance. This is due to the fact that the trees were small when the simulation started. Even without the agroforestry sub-model, the trees did not experience any water limitation. Hence, an additional water source for the trees does not directly influence its simulated growth. The additional water input to the tree grid point can be seen in Figure 3 (green line). This leads to no change in simulated evapotranspiration or percolation, but influences the soil water contents (Figure 4 and magenta lines in Figure 3).

However, if the trees experienced water limitation, a stronger impact of the agroforestry sub-model on the simulated tree growth and water balance would be expected.

In this simulation, the agroforestry sub-model has more impact on the simulation of the crop grid points. The leaf are index (Figure 7) and the biomasses (Figure 10) of the crop are reduced when the agroforestry sub-model is applied.

The water loss due to the agroforestry sub-model (red line in Figure 8) mostly influences percolation and evapotranspiration (yellow and cyan lines in Figure 8). Figures 11 and 12 show that the agroforestry module has a higher impact on the simulated transpiration than on the evaporation. The simulated soil water contents (Figure 9 and magenta lines of Figure 8) are hardly changed due to the application of the agroforestry sub-model.

5 Outlook

The agroforestry sub-model of Expert-N 5.0 can be applied to simulate the interaction between trees and crops within a agroforestry system. Some more processes, e.g. competition for nitrogen and hydraulic lift of the trees, should still be included. A comparison with measured data will be one of the next steps.

Literature

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