Buffering soil water supply to crops by hydraulic equilibration in conservation agriculture with deep-rooted trees: application of a process-based tree–soil–crop simulation model to parkland agroforestry in Burkina Faso

Meine van Noordwijk*[1], Rachmat Mulia[1], Jules Bayala[2]

[1] World Agroforestry Centre, ICRAF Southeast Asia, Bogor, Indonesia

[2] World Agroforestry Centre, ICRAF West and Central Africa, Bamako, Mali

***Corresponding author:** m.vannoordwijk@cgiar.org

Farmers deal with risks such as weather, pests, diseases, costs of inputs, market prices of products, (family) labour availability, policies regulating land use and, in some contexts, open interpersonal conflict. Perennial components of agricultural systems, especially trees, provide buffer and filter functions that modify, and generally reduce, the farmers' sensitivity to such external variables. Maintaining a diversity of activities is a time-tested approach to reducing risks (van Noordwijk et al. 1994). The inclusion of trees that provide annual harvests of fruits or long-term high-value timber can reduce risk, even if the trade-off in resource capture is essentially neutral (Santos-Martin and van Noordwijk 2011). Trees shelter farmers from climate variability and assist in adaptation to longer-term trends (van Noordwijk et al. 2011a).

There is a need to assess how to optimise the net balance of tree–crop interactions in 'conservation agriculture with trees' (CAWT) systems under variable conditions. Process-based simulation models can quantify the buffering of soil water as a major factor in the climate sensitivity of cropping systems. Examples include research in West African parklands where the redistribution of water from deeper soil layers can partially offset the negative effects of shading (Bayala et al. 2008). Above-ground interactions between trees and crops have positive and negative components: shelter from wind assists crops, especially in the establishment phase, but shading reduces light capture. Below-ground effects (van Noordwijk et al. 2004) are highly complex, with competition and facilitation effects on water and nutrient capture, as well as positive and negative interactions with soil biota.

The combination of above-ground and below-ground tree–crop interactions on the soil water balance is of specific relevance in climates where rainfall in the early part of the growing season is uncertain (and thus positive effects on infiltration and shelter from wind help), while crop growth may exhaust available soil water in the top layers towards the end of the growing season.

The presence of deep-rooted components in the cropping system can, under such circumstances, provide relevant buffer functions by the process of hydraulic equilibration (Bayala et al. 2008). The balance of positive and negative effects may thus shift during the crop growing season (Fig. 1), while crop phenology and harvest index (harvestable biomass / total biomass) vary with distance from the trees.

Because the timing and amount of rainfall vary from year to year and the net effect of trees on soil structure takes time as they gradually increase in size and rooting depth, it is not easy to evaluate the full spectrum of the net effect of trees in CAWT. Simulation models, such as the Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model (van Noordwijk et al. 2011 b), can help.

WaNuLCAS consists of a core set of resource capture modules and a set of additional modules to deal with specific additional effects (Fig. 2).

We developed WaNuLCAS applications for parkland agroforestry in Burkina Faso, the study site of Bayala et al. (2008).

The parameterisation of tree and crop variables at the site is incomplete, but the model can provide response functions over rainfall gradients for trees with various rooting patterns, with or without effects on hydraulic redistribution. An initially surprising result of comparisons of runs with and without hydraulic equilibration is that the effects on predicted tree performance exceed effects on crop growth, leading to more intense shading and negative overall effects on crop growth in many situations. As hydraulic equilibration depends on the presence of roots as conductors but not on active uptake, details of tree phenology have a large effect; and trees that drop their leaves during the crop growing season, such as *Faidherbia albida*, favour crop growth and yield.

Differential effects on crop harvest index with increasing distance from the tree stem reflect details of the way each individual rainy season unfolds. In some years there is not enough recharge of groundwater for hydraulic equilibration to function, but in other years late rains make the crop less dependent on such equilibration.

Ongoing analysis of the oxygen isotope signature of rainfall, groundwater and tree stem flow at the site will allow a more detailed test of model validity in the near future. Use of a dynamic root growth module along the lines of Mulia et al. (2010) will help to identify the specific clues to look for in climate change predictions if we want to evaluate the use of trees to reduce human vulnerability.

Keywords

Africa, agroforestry, climate variability, conservation agriculture with trees, WaNuLCAS

Figure 1. Schematic representation of positive (+) and negative (–) tree–crop (t/c) interactions during a growing season, based on effects on infiltration, hydraulic redistribution, shading, crop phenology and harvest index.

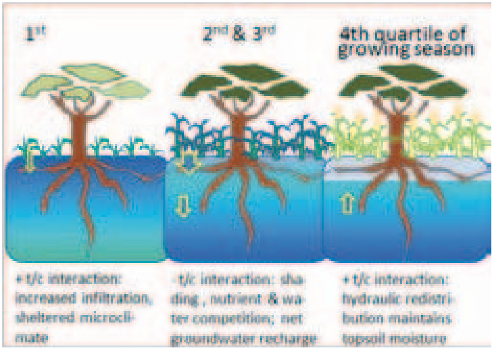
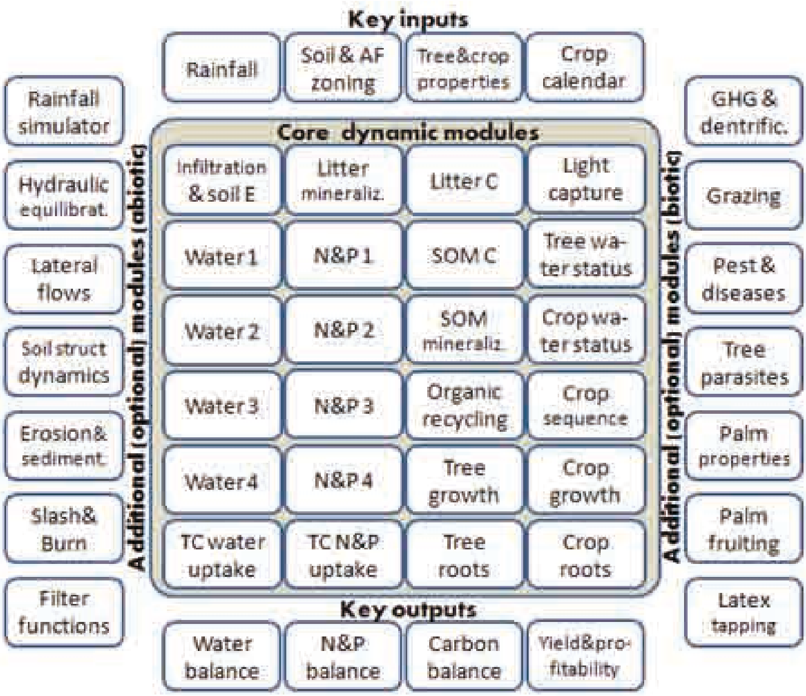


Figure 2. Core and additional modules that relate inputs to outputs in version 4 of the WaNuLCAS model (van Noordwijk et al. 2011b).



References

Bayala J, Heng LK, van Noordwijk M, Ouedraogo SJ. 2008. Hydraulic redistribution study in two native tree species of agroforestry parklands of West African dry savanna. Acta Oecologia 34: 370–378.

Mulia R, Dupraz C, van Noordwijk M. 2010. Reconciling root plasticity and architectural ground rules in tree root growth models with voxel automata. Plant and Soil 337: 77–93.

Santos-Martin F, van Noordwijk M. 2011. Is native timber tree intercropping an economically feasible alternative for smallholder farmers in the Philippines? Australian Journal of Agricultural and Resource Economics 55: 257–272.

Van Noordwijk M, Dijksterhuis G, Van Keulen H. 1994. Risk management in crop production and fertilizer use with uncertain rainfall: how many eggs in which baskets. Netherlands Journal of Agricultural Science 42: 249–269.

Van Noordwijk M, Cadisch G, Ong CK, eds. 2004. Belowground interactions in tropical agroecosystems. CAB International, Wallingford, UK.

Van Noordwijk M, Hoang MH, Neufeldt H, Öborn I, Yatich T, eds. 2011a. How trees and people can co-adapt to climate change: reducing vulnerability through multifunctional agroforestry landscapes. World Agroforestry Centre (ICRAF), Nairobi.

Van Noordwijk M, Lusiana B, Khasanah N, Mulia R. 2011b. WaNuLCAS version 4.0: Background on a model of water nutrient and light capture in agroforestry systems. World Agroforestry Centre (ICRAF), Bogor, Indonesia.