Chapter 2
Overview of the model

Before we give a detailed description of model assumptions and formulation in chapter 3, we will give an overview of the model here (Fig. 1.2).

The model is formulated in the STELLA Research modeling environment and thus remains open to modifications. Emphasis is placed on belowground interactions, where competition for water and nutrients (nitrogen and phosphorus) is based on the effective root length densities of both plant components and current demand by tree and crop.

Simulations require the prior definition of a soil profile and its soil physical and chemical properties per layer, of a degree of slope and hence lateral interactions, and of the climate.

Agroforestry systems are defined on the basis of spatial zones and a calendar of events for each zone, including growing and harvesting trees or crops, fertilizer use or slash-and-burn land clearing.

2.1 Model features

A key feature of the model is the description of uptake of water and nutrients (N and P) on the basis of root length densities of the tree(s) and the crop, plant demand factors and the effective supply by diffusion at a given soil water content. De Willigen and Van Noordwijk (1994) and Van Noordwijk and Van de Geijn (1996) described underlying principles.

The model was developed to emphasize the common principles underlying a wide range of tree-crop agroforestry systems in order to maximize the cross-fertilization between research into these various systems and explore a wide range of management options. The model can be used for agroforestry systems ranging from hedgerow intercropping (alley cropping) on flat or sloping land (contour hedgerow intercropping), taungya-type transitions into tree-crops, via (relay-planted) fallows to isolated trees in parkland systems. Figure 2.1 shows the different modules available inside WaNuLCAS model.

Agroforestry systems. The model represents a four-layer soil profile, with four spatial zones, a water, nitrogen and phosphorus balance and uptake by a crop (or weed) and up to three (types of) tree(s). The model can be used both for simultaneous and sequential agroforestry systems and may help to understand the continuum of options ranging from 'improved fallow' via relay planting of tree fallows to rotational and simultaneous forms of 'hedgerow intercropping'. The model explicitly incorporates management options such as tree spacing, pruning regime and choice of species or provenance. The model includes various tree characteristics, such as root distribution, canopy shape, litter quality, maximum growth rate and speed of recovery after pruning.

If applied to hedgerow intercropping, the model allows for the evaluation of different pruning regimes, hedgerow tree spacing and fertilizer application rates. When applied to rotational fallow systems, the 'edge' effects between currently cropped parts of a field and the areas where a tree fallow is growing can be simulated. For isolated trees in parkland systems, equidistant zones around individual trees can be 'pooled' and the system as a whole can be represented by a number of circles (of different radius) with a tree in the middle (further explanation is given in section 3.1).

Climate effects are mainly included via daily rainfall data, which can be either read from a spreadsheet or generated on the basis of daily probability of rainfall and a division between 'heavy', and 'light' rains. Average temperature and radiation are reflected in 'potential' growth rates. 'Thermal time' is reflected in the speed of phenological development. Soil temperature is explicitly used as a variable influencing decomposition and N and P mineralization.

Soil is represented in four layers, the depth of which can be chosen, with specified soil physical properties and initial water and nitrogen contents.

The **Water balance** of the system includes rainfall and canopy interception, with the option of exchange between the four zones by run-on and run-off as well as subsurface lateral flows, surface evaporation, uptake by the crop and tree and leaching. Vertical as well as horizontal transport of water is included; an option is provided to incorporate (nighttime) 'hydraulic equilibration' via the tree root system, between all cells in the model.

The **Nitrogen and Phosphorus balance** of the model includes inputs from fertilizer (specified by amount and time of application), atmospheric N fixation, mineralization of soil organic matter and fresh residues and specific P mobilization processes. Uptake by crop and tree is allocated over yields which are exported from the field / patch and recycled residues. Leaching of mineral N and P is driven by the water balance, the N concentrations and the apparent adsorption constant in each layer, thus allowing for a 'chemical safety net' by subsoil nutrient (including nitrate) adsorption.

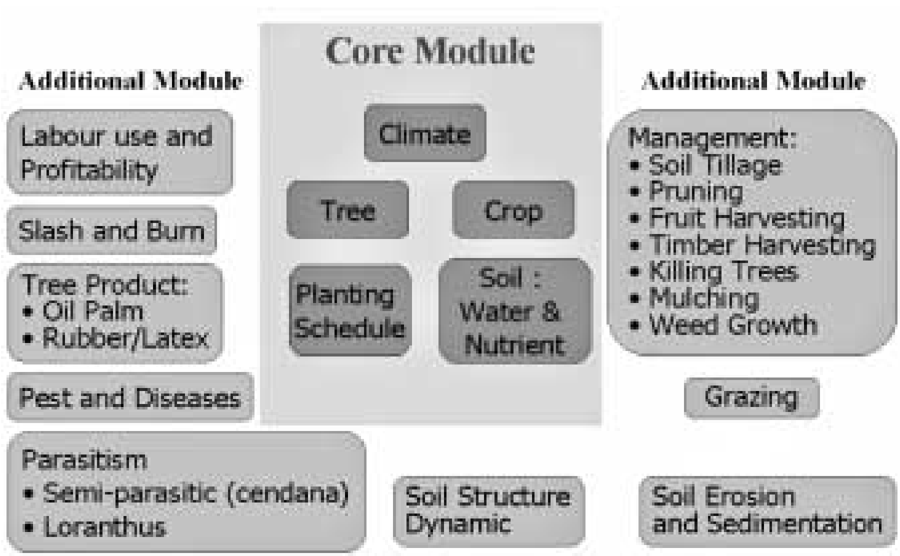

Figure 2.1 Schematic diagram of different modules inside WaNuLCAS model.

Growth of both plants ('crop' and 'tree') is calculated on a daily basis by multiplying potential growth (which depends on climate) with the minimum of four 'stress' factors, one for shading, one for water limitation, one for nitrogen and one for phosphorus. For trees a number of allometric equations (which themselves can be derived from fractal branching rules) is used to allocate growth over tree organs.

Uptake of both water and nutrients by the tree and the crop is driven by 'demand' in as far as such is possible by a zero-sink uptake model on the basis of root length density and effective diffusion constants:

$$uptake = \min(demand, potential\ uptake) \qquad \textbf{[2]}$$

For water the potential uptake at a given root length density and soil water content is calculated from the matric flux potential of soil water.

Demand for nitrogen uptake is calculated from empirical relationships of nutrient uptake and dry matter production under non-limiting conditions[1], a 'luxury uptake'[2], a possibility for compensation of past uptake deficits and an option for N fixation (driven by the Ndfa parameter, indicating the part of the N demand which can be met from atmospheric fixation).

Competition for water and nutrients is based on sharing the potential uptake rate for both (based on the combined root length densities) on the basis of relative root length multiplied by relative demand:

$$PotUpt(k) = \min\left[\frac{Lrv(k) * Demand(k) * PotUpt\left(\sum Lrv\right)}{\sum_{k=1}^{n}\left(Lrv(k) * Demand(k)\right)}, PotUpt\left(Lrv(k)\right)\right] \qquad \textbf{[3]}$$

where PotUpt gives the potential uptake rate for a given root length density L_{rv}.

This description ensures that uptake by species k is:

1. proportional to its relative root length density L_{rv} if demand for all components is equal,

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[1] The assumptions are 5% N in dry matter up to a closed crop canopy (s reached at an aboveground biomass of about 2 Mg ha^{-1}) and 1%N in new dry matter after that point with target N:P ratio = 10

[2] An assumption that growth will not be reduced until N content falls below 80% of demand

2. never more than the potential uptake by *i* in a monoculture with the same L_{rv},
3. not reduced if companion plants with a high root length density have zero demand (e.g. a tree just after pruning).

At this stage we apply this procedure to four species (n=4, i.e. 3 trees and a crop or weed in each zone), but the routine can be readily expanded to a larger number of plants interacting.

Root growth is represented for the crop by a logistic increase of root length density in each layer up till flowering time and gradual decline of roots after that time. A maximum root length density per layer is given as input. The model also incorporates a 'functional equilibrium' response in shoot/root allocation of growth, and a 'local response' to shift root growth to favourable zones. For the tree, root length density in all zones and layers can be assumed to be constant, thus representing an established tree system with equilibrium of root growth and root decay or can follow dynamic rules roots similar to those for crop.

The **Soil Organic Matter** module includes litter layer and organic matter. Both has three main pools (Active, Slow and Passive), following the terminology and concepts of the CENTURY model.

Light capture. Light capture is treated on the basis of the leaf area index (LAI) of all components and their relative heights, in each zone. Potential growth rates for conditions where water and nutrient supply are non-limiting are used as inputs. This can be potentially derived from other models. Actual growth is determined by the minimum of shade, water and nutrient stress.

2.2 Model organization

Stella allows the user three perspectives on a model:

1. On the upper layer, general information is provided, key parameters can be modified (Fig. 2.2A) and output can be obtained in the form of graphs and tables (Fig. 2.2B). Figure 2.4 shows example of output graphs.
2. On the middle layer (Fig. 2.3 A-B), the model is presented as a complete compartment - flow diagram, with all equations entered at the respective 'converters'; double arrows indicate 'flows' from 'pools' in rectangles, while single lines indicate a flow of information; this is the working level for developing or modifying the model; a 1:1 relation is maintained between the diagram and the model relationships,

3. A listing of the model equations, with comments added.

At the middle level, the model can be arranged in sectors. To facilitate the process of finding parameters in the model, we made sure that all parameters in a sector start with letters referring to the sector. This way, an alphabetic listing of parameters as the Stella shell does, gets functional significance. In chapter 3 we will start using the names of model parameters in WaNuLCAS. A selection of parameters (all those which are important as input values to be specified by the user) is given in Appendix 7.

In Stella multiple representations of similar structures can be obtained by using arrays. In WaNuLCAS we use arrays for the 'zones' and in some cases, for the different soil layers. We also use arrays for nutrients (N and P) as they can be treated in parallel. Despite the symmetry in the uptake description between water and nitrogen, we found that there are enough differences to merit separate representation in the model, rather than a generic 'belowground resources'. A number of parameters dependent on crop type are in an array called 'crop', and are utilized based on the crop sequence specified (see 3.1.3). To find out the various arrays used in the model, see the array editor within the STELLA model.

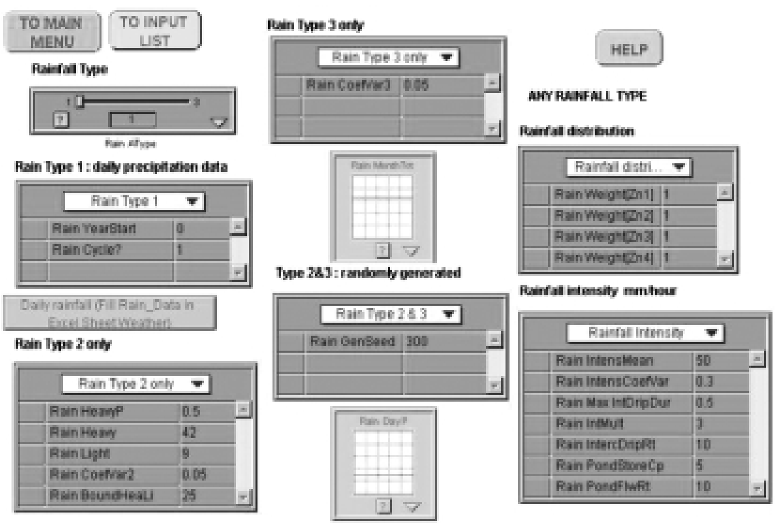

Figure 2.2A Upper level view on the WaNuLCAS model options for setting input values numerically or in graph (table) form; the buttons 'to main menu' and 'to input list' allow one to navigate through the input section

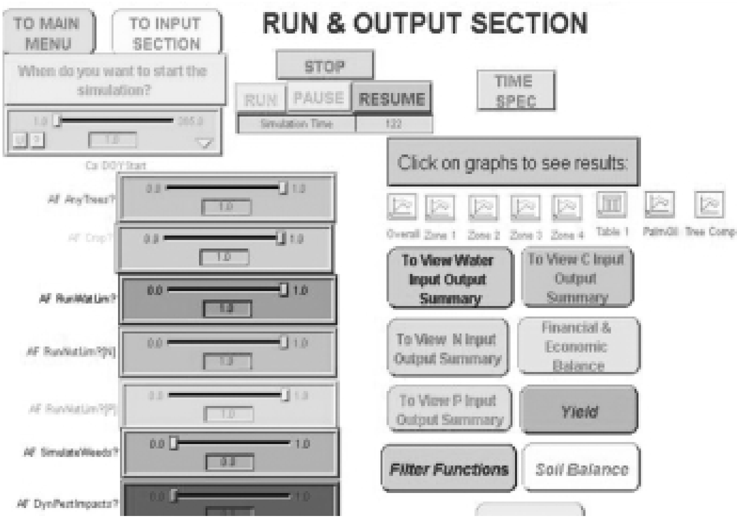

Figure 2.2B Upper level view on the WaNuLCAS model with example of output graphs and tables

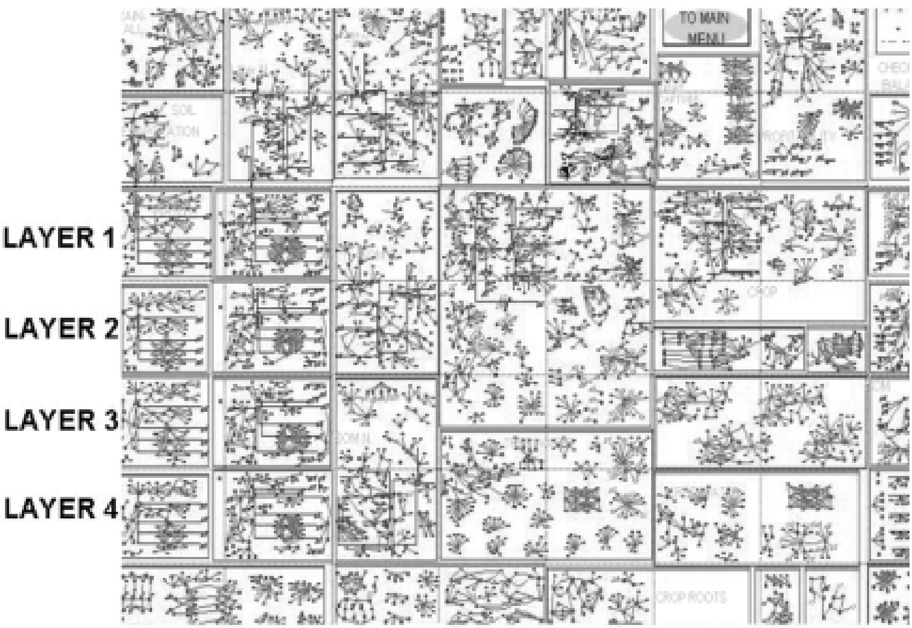

Figure 2.3A A Middle level overview of the WaNuLCAS model in version 1.2

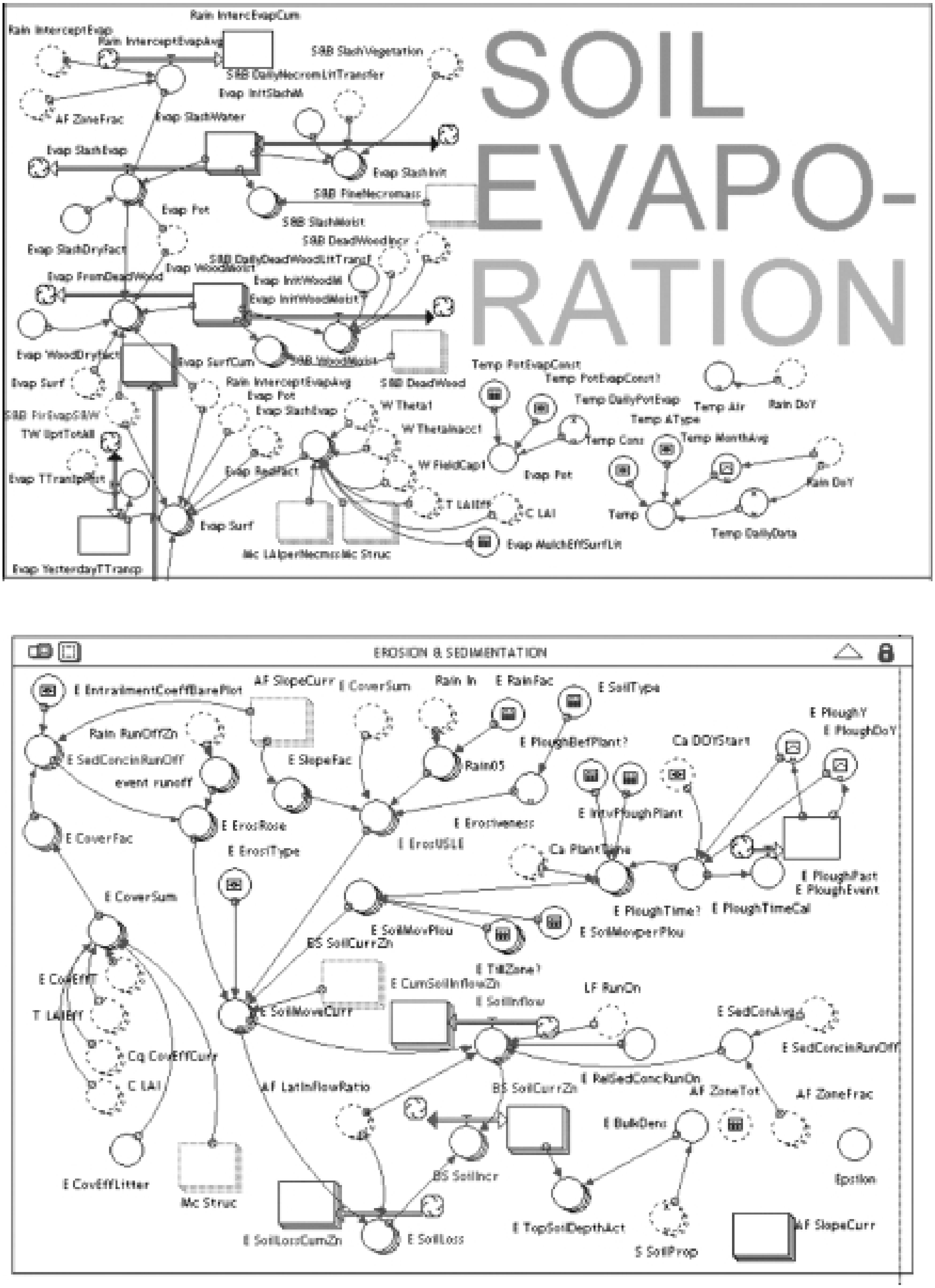

Figure 2.3B Middle level view on the WaNuLCAS model with examples of 2 sectors

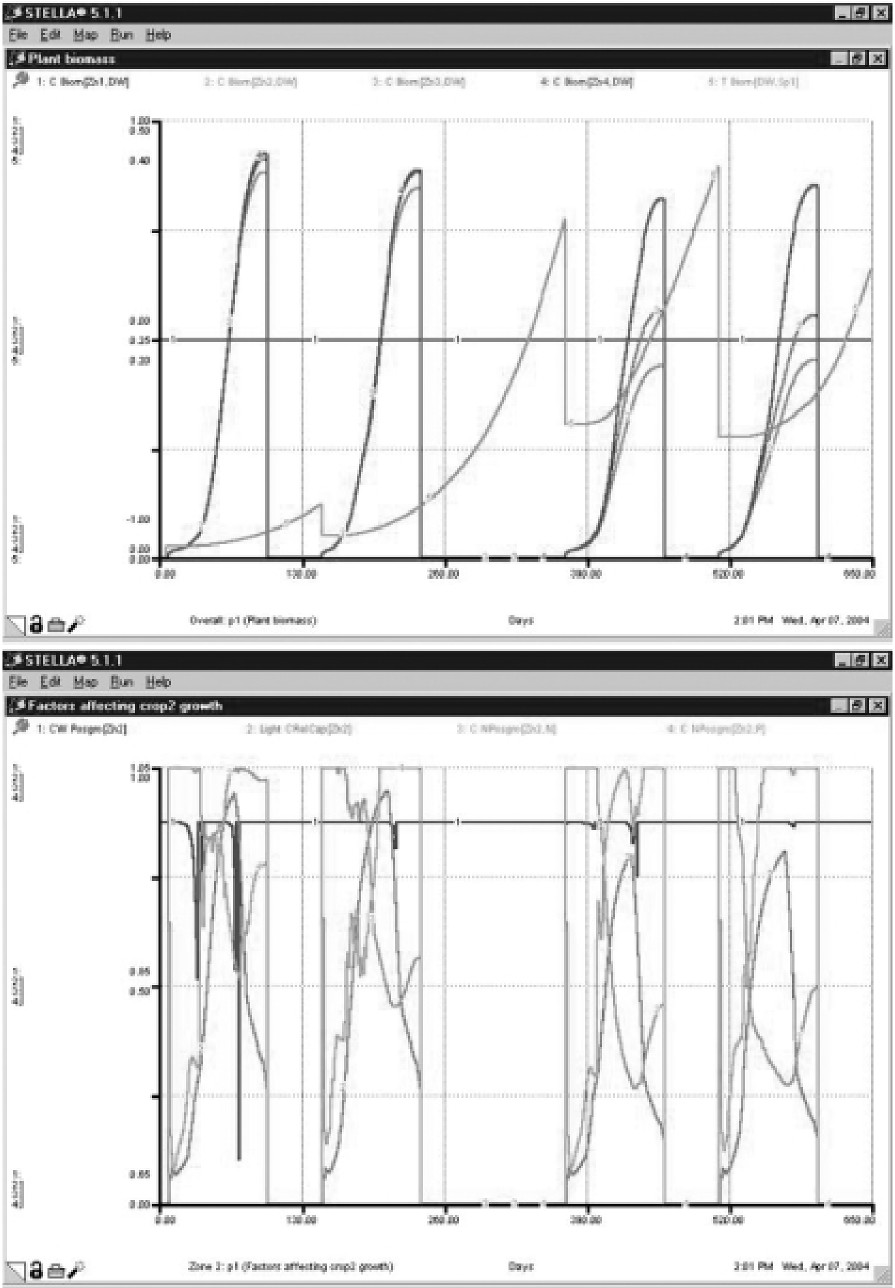

Figure 2.4 Example of output graphs