References

Akyeampong E, Duguma B, Heineman AM, Kamara CS, Kiepe P, Kwesiga F, Ong CK, Otieno HJ and Rao MR (1995) A sysntesis of ICRAF's research on alley cropping. *In*: Alley Farming Research and Development. AFNETA, Ibadan, Nigeria. Pp 40 – 51.

Akyeampong E, Duguma B, Heineman AM, Kamara CS, Kiepe P, Kwesiga F, Ong CK, Otieno HJ and Rao MR (1995) A synthesis of ICRAF's research on alley cropping. *In*: Alley Farming Research and Development. AFNETA, Ibadan, Nigeria. pp 40-51.

Arah J and Hodnett M (1997) Approximating soil hydrology in agroforestry models. Agroforestry Forum 8(2): 17-20.

Bayala J, van Noordwijk M, Lusiana B, Ouédraogo S J, Teklehaimanot Z (2004) Separating the tree-soil-crop interactions in agroforestry parkland systems in Sapone (Burkina Faso) using WaNuLCAS. ICRAFSEA – INERA. Poster presented at 1st World Congress of Agroforestry, 27 June – 2 July 2004, Orlando – Florida, USA.

Boughton, WC (1999) A daily rainfall generating model for water yield and flood studies. Cooperative research centre for catchment hydrology. 21 pp.

Breman H and Kessler JJ (1997) The potential benefits of agroforestry in the Sahel and other semi arid regions. European Journal of Agronomy 7: 25 33.

Burgess SSO, Adams MA, Turner NC and Ong CK (1998) Redistribution of soil water by tree root systems. Oecologia 3(115): 306-311.

Cadisch G, Rowe E and van Noordwijk M (1997) Nutrient harvesting - the tree-root safety net. Agroforestry Forum 8(2): 31-33.

Caldwell RM, Pachepsky YA and Timlin DJ (1996) Current research status on growth modeling in intercropping. *In*: O.Ito *et al*. (*Eds*) Dynamics of Roots and Nitrogen in Cropping Systems of the Semi-Arid Tropics. Japan International Research Center for Agricultural Sciences. pp 617-635.

Cannell MGR, Mobbs DC and Lawson GJ (1998) Complementarity of light and water use in tropical agroforests. II. Modelled theoretical tree production and potential crop yield in arid to humid climates. Forest Ecology and Management 102: 275 282.

Cannell MGR, van Noordwijk M and Ong CK (1996) The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire. Agroforestry Systems 33: 1-5.

Dawson TE (1993) Hydraulic lift and water use by plants: implications for water balance, performance and plant plant interactions. Oecologia 95: 565 574.

De Willigen P and Van Noordwijk M (1987) Roots for plant production and nutrient use efficiency, Doctoral thesis Agricultural University Wageningen 282 pp.

De Willigen P and Van Noordwijk M (1989). Model calculations on the relative importance of internal longitudinal diffusion for aeration of roots of non-wetland plants. Plant Soil 113: 111-119

De Willigen P and Van Noordwijk M (1989) Rooting depth, synchronization, synlocalization and N use efficiency under humid tropical conditions. *In*: Van de Heide, J. (*eds*) Nutrient Management for Food Crop Production in Tropical Farming Systems. Institute for Soil Fertility, Haren, pp. 145 156.

De Willigen P and Van Noordwijk M (1991) Modeling nutrient uptake: from single roots to complete root systems. in: F.W.T. Penning de Vries, HH van Laar and MJ Kropff (*eds*) Simulation and Systems Analysis for Rice Production (SARP). Simulation Monographs, PUDOC, Wageningen. p. 277-295.

De Willigen P and Van Noordwijk M (1994) Diffusion and mass flow to a root with constant nutrient demand or behaving as a zero-sink. Soil Sci. 157: 162-175.

De Willigen P, Nielsen NE, Claassen N and Castrignanò AM (2000) Modelling water and nutrient uptake. In: A.L. Smit, A.G. Bengough, C. Engels, M. Van Noordwijk, S. Pellerin and Van der Geijn (*eds*) 2000. Root Methods, a Handbook. Springer Verlag, Berlin. pp 509-544

Duan J, Sikka AK, Grant GE (1995) A Comparison of stochastic models for generating daily precipitation at the H.J. Andrews Experimental Forest. Northwest Science 69 (4): 318-329.

Geng S, De Vries P, Supit FWTI (1986) A simple method for generating daily rainfall data. Agricultural and Forest Meteorology 36: 363-376.

Gijsman AJ, Oberson A, Tiessen H and Friesen DK (1996) Limited applicability of the CENTURY model to highly weathered tropical soils. Agron. J. 88: 894-903.

Gotelli ND and Graves GR (1996) Null Models in Ecology. Smithsonian Institution Press, Washington, 357 pp.

Hairiah K, Purnomosidhi P, Khasanah N, Nasution N, Lusiana N, and van Noordwijk M (2003) Pemanfaatan Bagas dan Daduk Tebu untuk Perbaikan Status Bahan Organik Tanah dan Produksi Tebu di Lampung Utara: Pengukuran dan Estimasi Simulasi WaNuLCAS (Use of bagas and sugarcane trash to improve soil organic matter status and sugarcane yield in North Lampung: field measurement and simulation by WaNuLCAS model) . Agrivita Vol. 25 No. 1

Hannon B and Ruth M (1994) Dynamic Modeling. Springer-Verlag, New York. 248 pp.

Howard SB, Ong CK, Black CR and Khan AAH (1997) Using sap flow gauges to quantify water uptake by tree roots from beneath the crop rooting zone in agroforestry systems. Agrofor. Syst. 35: 15 29.

Kropff MJ and Van Laar HH (1993) Modeling crop - weed interactions. CAB International, Wallingford (UK).

Lott JE, Khan AAH, Ong CK and Black CK (1996) Sap flow measurements of lateral roots in agroforestry systems. Tree Physiol 16: 995 1001.

Mobbs DC, Cannell MGR, Crout NMJ, Lawson GJ, Friend AD and Arah J (1998) Complementarity of light and water use in tropical agroforests. I. Theoretical model outline, performance and sensitivity. Forest Ecology and Management 102: 259 274.

Muetzelfeldt R and Taylor J (1997) The suitability of AME (Agroforestry Modeling Environment) for agroforestry modeling. Agroforestry Forum, 8(2) 7-9.

Muthuri, C. W. (2004). Modelling leaf phenology effects on water use and growth; In Impact of agroforestry on crop performance and water resources in semi-arid central Kenya. PhD thesis, Jomo Kenyatta University of Agriculture and Technology, Kenya, pp 222-251.

Myers B, Van Noordwijk, M and Vityakon P (1997). Synchrony of nutrient release and plant demand: plant litter, soil environment and farmer management options. *in*: G. Cadisch and K.E. Giller (*eds*) Driven by Nature: Plant Litter Quality and Decomposition. CAB International, Wallingford (UK) pp. 215 - 229.

Myers RJK, Palm CA, Cuevas E, Gunatilleke IUN and Brossard M (1994) The synchronisation of nutrient mineralisation and plant nutrient demand. *in*: P.L. Woomer and M.J. DSwift (*Eds.*) The Biological Management of Tropical Soil Fertility. Johm Wiley, Chichester (UK) pp 81-116.

Ong CK 1995. The 'dark side' of intercropping: manipulation of soil resources. In: Sinoquet H and Cruz P (*eds*.) Ecophysiology of Tropical Intercropping, 482 pp. Institute National de la Recherche Agronomique, Paris (France).

Ong CK and PA Huxley (*Eds*.). (1996) Tree-Crop Interactions - a Physiological Approach. CAB International, Wallingford (UK).

Palm CA, Alegre JC, Arevalo L, Mutuo PK, Mosier AR and Coe R (2002) Nitrous oxide and methane fluxes in six different land use systems in the Peruvian Amazon. Global Biogeochemical Cycles 16(4), 1073.

Parton WJ, Ojima DS, Cole CV and Schimel DS (1994) A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. *In*: Quantitative Modeling of Soil Forming Processes. Special Publication 39, Soil Science Society of America, Madison WI, USA, pp 147-167.

Pickering NB, Stedinger JR, Haith DA (1988). Weather input for nonpoint source pollution models. J. Irrig. Drain. Eng. 114 (4): 674-690.

Radersma S and Ong CK (2004) Spatial distribution of root length density and soil water of linear agroforestry systems in sub-humid Kenya: implications for agroforestry models. Forest Ecology and Management, 188(1-3), 77-89

Rao MR, Nair PK and Ong CK (1997) Biophysical interactions in tropical agroforestry systems. Agroforestry Systems 38: 3 - 49.

Richardson CW (1981) Stochastic generation of daily precipitation, temperature, and solar radiation. Water Resource Res. 17(1): 182-190.

Rodriguez RN (1977). A guide to the Burr type XII distribution. Biometrika 64: 129-134.

Rowe EC, Hairiah K, Giller KE, Van Noordwijk M and Cadisch G (1999) Testing the safety-net role of hedgerow tree roots by 15N placement at depths.. Agroforestry Systems 43: 81-93.

Rykiel EJ (1996) Testing ecological models: the meaning of validation. Ecological Modeling 90: 229-244.

Sanchez P (1995) Science in agroforestry. Agroforestry Systems 30: 5-55.

Scotter DR, Horne DJ, Green SR (2000). A procedure for generating daily rainfall and evaporation data: an evaluation and some applications. Journal of Hydrology (NZ) 39(1): 65-82.

Selker JS, Haith DA (1990). Development and testing of single-parameter precipitation distributions. Water Resources Res. 26: 2733-2740.

Shepherd KD and Soule MJ (1998) Soil fertility management in West Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agriculture, Ecosystems & Environment (in press).

Sinoquet H, Adam B, Rivet P and Godin C (1997) Interactions between light and plant architecture in an agroforestry walnut tree. Agroforestry Forum, 8(2) 37-39.

Smith DM, Jackson NA, Roberts JM and Ong CK (1998) Reverse flow in tree roots and downward siphoning of water by Grevillea robusta. Functional Ecology 2(13): 256-264.

Suprayogo D, Widianto and Lusiana B (2002) Diagnosis Kesehatan Bertani Berbasis Pohon: Apakah air dan hara tanah digunakan secara efisien. *In*: S.M. Sitompul and S.R. Utami (*eds*) Akar Pertanian Sehat: Konsep dan Pemikiran. Biological Management of Soil Fertility (BMSF), Brawijaya University, Malang (Indonesia). p 117-129

Suprayogo D, Widianto, Cadish G, and van Noordwijk M (2003) A Pedotransfer resource database (PTFRDB) for tropical soils : test with the water balance of WaNuLCAS *in*: D Post (*eds*) Proceedings of the 2003 MODSIM Conference – Volume 1. Townsville, Australia. p 584-589.

Suprayogo D (2000) Testing the Safety - Net Hypothesis in Hedgerow Intercropping: water balance and mineral - N leaching in the humid tropics. PhD thesis, Imperial College London, Wye Campus, UK, 316 pp.

Tomich TP, Van Noordwijk M, Budidarseno S, Gillison A, Kusumanto T, Murdiyarso D, Stolle F and Fagi AM (1998b) Alternatives to Slash-and-Burn in Indonesia, Summary report and synthesis of Phase II. ICRAF S.E. Asia, Bogor, Indonesia, 139 pp.

Tomich TP, Van Noordwijk M, Vosti S and Whitcover J (1998a) Agricultural Development with Rainforest Conservation: Methods for Seeking Best Bet alternatives to Slash-and-Burn, with Applications to Brazil and Indonesia. Agricultural Economics 19: 159-174.

Van Noordwijk M and De Willigen P (1984). Mathematical models on diffusion of oxygen to and within plant roots, with special emphasis on effects of soil-root contact: II. Applications. Plant Soil 77: 233-241

Van Noordwijk M and Brouwer G (1988). Quantification of air-filled root porosity: a comparison of two methods. Plant Soil 111: 255-258

Van Noordwijk M and Brouwer G (1993). Gas-filled root porosity in response to temporary low oxygen supply in different growth stages. Plant Soil 152: 175-185

Van Noordwijk M, Rahayu S, Williams SE, Hairiah K, Khasanah N, Schroth G (2003) Crop and tree root-system dynamics. *In:* M. van Noordwijk, G. Cadisch, C.K. Ong (*eds*) BelowGround Interaction in tropical Agroecosystems: Concepts and Models with multiple plant component, CABI, Wallingford, UK

Van Noordwijk M (1989) Rooting depth in cropping systems in the humid tropics in relation to nutrient use efficiency. *In*: J. van der Heide (ed.) Nutrient Management for Food Crop Production in Tropical Farming Systems. Institute for Soil Fertility, Haren. p 129-144.

Van Noordwijk M (1996a) A simple model to quantify mulch and shade effects. *In*: C.K. Ong and P.A. Huxley (*Eds*.). Tree-Crop Interactions - a Physiological Approach. CAB International, Wallingford (UK). pp 51-72.

Van Noordwijk M (1996b) Models as part of agroforestry research design. AGRIVITA 19: 192-197.

Van Noordwijk M and Brouwer G (1997) Roots as sinks and sources of carbon and nutrients in agricultural systems. *in*: L. Brussaard and R. Ferrera-Cerrato (*eds*.) Soil Ecology in Sustainable Agricultural Systems. CRC Lewis Publ., Boca Raton. pp 71-89.

Van Noordwijk M and Cadisch G (2002) Access and excess problems in plant nutrition. Plant and Soil 247:25-40

Van Noordwijk M and Lusiana B (1999) WaNuLCAS, a model of water, nutrient and light capture in agroforestry systems. Agroforestry Systems 43: 217-242.

Van Noordwijk M and Ong CK (1999) Can the ecosystem mimic hypotheses be applied to farms in African savannahs?.Agroforestry Systems 45: 131-158.

Van Noordwijk M and Purnomosidhi P (1995) Root architecture in relation to tree soil crop interactions and shoot pruning in agroforestry. Agroforestry Systems 30: 161-173.

Van Noordwijk M and Van de Geijn SC (1996) Root, shoot and soil parameters required for process-oriented models of crop growth limited by water or nutrients. Plant and Soil 183: 1-25.

Van Noordwijk M, Hairiah K, Lusiana B and Cadisch G (1998a) Tree - Soil - Crop Interactions in Sequential and Simultaneous Agroforestry Systems. *in*: L. Bergstrom and H. Kirschner (Ed.) Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems. CAB International, Wallingford (UK). pp 173-190.

Van Noordwijk M, Lawson G, Groot JJR, Hairiah K, (1996) Root distribution in relation to nutrients and competition. *In*: C.K. Ong and P.A. Huxley (*Eds*.). Tree-Crop Interactions - a Physiological Approach. CAB International, Wallingford (UK). pp 319-364.

Van Noordwijk M, Radersma S and Lusiana B (1999) Modelling root architecture and phosphorus uptake in agroforestry. Agroforestry Forum 9(4) 28-30.

Van Noordwijk M, Van Roode M, McCallie EL and Lusiana B (1998b) Erosion and sedimentation as multiscale, fractal processes: implications for models, experiments and the real world. *In*: F. Penning de Vries, F. Agus and J. Kerr (*Eds*.) Managing Soil Erosion. CAB International, Wallingford. 223-253.

Vandermeer JH (1989) The Ecology of Intercropping. Cambridge University Press, Cambridge.

Verchot LV, Davidson EA, Cattânio JH and Ackerman IL (2000) Land-use change and biogeochemical controls of methane fluxes in soils of eastern Amazonia. Ecosystems 3, 41-56.

Verchot LV, Davidson EA, Cattânio JH, Ackerman IL, Erickson HE and Keller M (1999) Land use change and biogeochemical controls of nitrogen oxide emissions from soils in eastern Amazonia. Global Biogeochemical Cycles 13, 31-46.

Verchot LV, Mosier A, Baggs EM and Palm CA (2004) Soil–Atmosphere Gas Exchange in Tropical Agriculture: Contributions to Climate Change. *In*: M. Van Noordwijk, G. Cadisch and C.K. Ong (*Eds*.) Belowground Interactions in Tropical Agroecosystems, CAB International, Wallingford (UK), in press

Wösten JHM, A Lilly, A Nemes and C Le Bas (1998) Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning. Report 156, SC-DLO, Wageningen (the Netherlands), 106 pp.

Wösten JMH, Finke PA and Jansen MJW (1995) Comparison of class and continuous pedotransfer functions to generate soil hydraulic characteristics. Geoderma 66: 27-37.

Young A (1997) Agroforestry for Soil Management. 2nd ed. CAB International, Wallingford (UK). 320 pp.

Young A, Menz K, Muraya P and Smith C (1990) SCUAF Soil changes under agroforestry. Computer program with user's handbook. Version 2. ICRAF, Nairobi (Kenya) 124 pp.

Young A, Menz K, Muraya P and Smith C (1998) SCUAF Version 4: A model to estimate soil changes under agriculture, agroforestry and forestry. ACIAR Technical Reports Series No. 41, ACIAR, Canberra (Australia). 49 pp.

Appendix

Appendix 1. Introduction to STELLA

STELLA is a flowchart-based modelling software. It enable users to construct model by drawing boxes, circles and arrows. **STELLA** is similar to ModelMaker.

During this session you will learn to build a model, step by step using **STELLA**. The purpose of this session is to familiarize yourself with **STELLA** and to learn how to use basic features of **STELLA** for simulation modelling.

<u>Initiating **STELLA**</u>

Start **STELLA** by clicking on its icon on the window screen. You will be automatically inside a new file.

STELLA is a multi-level hierarchical environment. It consists of 3 layers [3]:

- Interface Layer; which contain input output relationship
- Map and Model Construction Layer; where you construct the model can be simulated, it is often refered to as the 'engine room' for the models you create
- Equation Layer; to view list of all equation of model elements and relations

<u>Move between layers</u>

- Currently you are in the second layer. You can move between layers by clicking on arrow at the top left hand corner.
- You will find all the layers are still empty because you have not construct anything.

Let's try building a simple model based on Trenbath (1984).

Trenbath formulated a simple model of restoration and depletion of 'soil fertility' during fallow and cropping periods, respectively.

'Soil fertility' is defined as a complex of effective nutrient supply and biological factors (diseases, weeds) affecting crop yield. Crop yield is assumed to be directly proportional to 'soil fertility'.

Assume during a cropping period soil fertility declines with a fraction D per crop, while during a fallow period soil fertility can be recreated with a fraction of R.

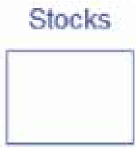
3 Version 9 and beyond has 4 layers:
- Interface Layer which contain input output relationship
- Map layer: to layout your thinking in the front of a map
- Model Construction Layer; where you construct the model can be simulated, it is often refered to as the
- Equation Layer; to view list of all equation of model elements and relations

<u>Constructing a model</u>

- Make sure you are in the second layer. You will notice a globe (world) icon underneath the arrow at the top left hand corner. On the top you will see 14 icons, starting with 'box' icon at the furthest left and 'ghost' at the furthest right.
- Make a variable of soil fertility. To do this, click on the box icon then click again anywhere on the empty space. Change the name from 'Noname1' into 'Soil Fertility' or any variable name you like. There are no restriction on length. What you have just made is called building blocks.

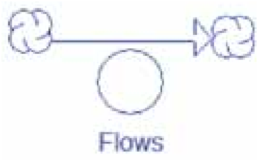
STELLA has 4 types of building box:

1. Stocks



Stocks are accumulations. They collect whatever flows into and out of them

2. Flows

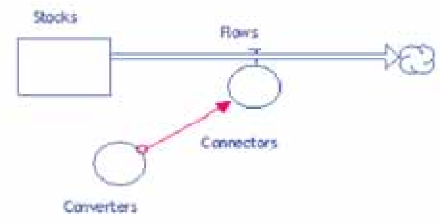


The job of flows is to fill and drain accumulation s. The unfilled arrow head on the flow pipe indicated the direction of the flow.

3. Converters

The converter serves a practical and handy role. It holds values for constants, defines external inputs to the model, calculates algebraic relationships and serves as the repository for graphical functions. In general it converts inputs into outputs.

4. Connectors



The job of the connector is to connect model elements.
This is an example of how building blocks are used.

Constructing a model (Continued.)

- Since 'Soil Fertility' will decrease during cropping year, you will have to make an outflow from 'Soil Fertility'. Name the flow as 'Depletion'.
- 'Depletion' depend on depleting factor (D), length of cropping year **and length of fallow year** (if it is a fallow year, depletion will not occur). Make 3 converters and name them as D, TimeCrop and TimeFallow. Connect all 3 converters to 'Depletion'
- Now you will need to define the relationship between those parameters into an equation in 'Depletion'. See what happen if you click twice on 'Depletion'.
- Click Cancel and see what happen if you click on the globe icon then clicking twice on 'Depletion'.
- You are now in equation box. Type out the following equation:

IF(MOD(TIME[4], (TimeCrop+TimeFallow)) <TimeCrop) THEN (Soil_Fertility*D) ELSE(0)1

Make sure there is a connection from 'Soil Fertility' to 'Depletion'

- You will see that all building blocks except 'Depletion' has question mark on them. They are asking for a value. Put the following value just for a try out. D=0.4, Soil fertility=10, TimeFallow=3, TimeCrop=3
- Now, do the same step for recreation factor, which is an inflow to 'Soil Fertility'. What do you think should be the equation in 'Recreation'? First try a constant value, for example put IF(MOD(TIME, (TimeCrop+TimeFallow)) > TimeCrop)THEN(0.2) ELSE(0)
- The Trenbath model used a 'saturation' function in which the recreation depends on the difference between current fertility and a maximum value (Finf), modified by a 'half-recovery time' Kfert, so we make converters for Finf (value e.g. 10) and Kfert (value e.g. 5): IF(MOD(TIME, (TimeCrop+TimeFallow)) >TimeCrop)THEN((Finf Soil_Fertility)*Soil_Fertility/(Finf-Soil_Fertility+Kfert*Finf)) ELSE(0)
- Now go to the third layer. You will now see the values and equations of your model.

Making an Output

- To make a graph click on graph icon (7th icon from left) and click again anywhere. A box named untitled graph will emerge.
- Click twice on the graph then select 'Soil Fertility' from Allowable Box. Click the arrow pointing to the right. Then click OK.
- You may do the same thing with table icon (8th icon from left)

Running the Program

- To run the program choose **Run** from Run Menu. You can also run the program by pressing **Ctrl-R** or clicking the running-man icon in the bottom left hand corner then click an arrow pointing to the right.
- To see the simulation result, click twice on the graph or table.
- You will notice that the simulation run until time 12 with Delta Time (DT)=0.25. You can change this by choosing **Time Spec** on Run Menu. Try putting DT=1 and length simulation to 50.
- Run the model again and see what happen.
- Try changing R and D value. At what value would they result in stable condition?

4 MOD(TIME,(TimeCrop+TimeFallow)) will give current time minus the already completed cycles. The early part of a new cycle is cropped, the latter part is fallow.

<u>Sensitivity Analysis</u>

STELLA has a sensitivity analysis option. Let's try to see how sensitive 'Soil fertility' to changes in 'Depletion'

- Choose **Sensi Spec** from Run Menu. Choose D from Allowable Box then click an arrow pointing to right.
- Click D on Selected Box, then fill the following value: Start=0.2, End=0.6. Click on **Set** then **OK**.
- Click twice on graph, then choose graph type as Comparative.
- Now Run the model and see the result.

<u>Exercises</u>

The model you have built is very simple. Now try adding other variables to add complexity into it. Below are several exercises you may like to try out.

- Add crop production into it. Assume crop production is linearly proportional to decreased in 'soil fertility'/depletion. Find the total crop production during simulation.
- Assume that in the sum of cropping time and fallow time is a constant over time (a constant cycle). Fallow time is a function of total cumulative production. If the cumulative production meet a certain target then continue with the same length of fallow time. If cumulative production below target you need to shortened the length of fallow time to make up for.
- Assume target production as a function of population density and food needed per capita

Appendix 2. User's guide to WaNuLCAS

Introduction

This user's guide is designed to help users in working with **WaNuLCAS** model. Throughout this document, we assumed users have a basic experience on using software under Microsoft Windows.

To be able to run WaNuLCAS reasonably well the recommended system requirements are:

- Pentium processor or better
- Microsoft Windows™ 95
- 64 MB RAM
- VGA display of at least 256 colors

There are three options for running WaNuLCAS:

1. Under STELLA demo, you can
   a. change most of the parameter values within the ranges set
   b. run the model and explore the result
2. Under STELLA Commercial Run Time (CRT), which is a 'stripped' version of Stella Research. You can:
   a. run the model
   b. change most of the parameter values within the ranges set (directly or by copying from EXCEL files), and
   c. save/save as to maintain modified parameters
   d. save graphs as pictures for printer
3. Under STELLA Research. In addition to the above you can also:
   a. modify parameters ('constant') not included in the input lists
   b. modify the parameter ranges
   c. save output tables as text files for further data handling with other software
   d. create new graphs or tables
   e. print a listing of all program equations
   f. modify the layout of the model
   g. modify equations, add or delete pools and flows, i.e. modify 'the model itself'.

If you do any modification, please keep track of changes made for any future report on your 'modified WaNuLCAS'.

This document deals with the second option that is running WaNuLCAS in Stella Regular/ Research version. A free downloadable version of Stella is available at **http://www.iseesystems.com/**. All option available except saving a file.

Installing WaNuLCAS

You may copy and decompress the WaNuLCAS model (WaNuLCAS.stm) and the MS Excel file (Wanulcas.xls) into any directory.

Starting WaNuLCAS

Initiate Excel. Open Wanulcas.xls. The Wanulcas.xls file contains a number of macros. The default setting in most MS Windows and MS Excel installations is to not allow such macros and to not even ask whether the user wants them or not. If your computer security settings don't allow any macro to run, you may need to change the security level for macros.

If you are working with MS Excel 2003, to change the security level go to "Tools" and "Macro" and choose "low", then close and re-open Wanulcas.xls. It will give a warning that the file contains a macro. Choose "enable macro".

If you working with MS Excel 2007, to change the security level for macros, follow the diagram below. This is to make sure the macro built to ease inputting parameters in the model is working properly.

Then run STELLA, it will automatically open a blank working model. Close it then open WaNuLCAS.stm from appropriate directory.

If you are working with STELLA 7 or 8, to update the linked input from Wanulcas.xls into WaNuLCAS.stm, click "Yes" when the question, "This model contain links. Re-establish link?", appears on your screen when you open WaNuLCAS.stm. Be sure that you already have EXCEL running in the background and Wanulcas.xls have already been opened.

STELLA only allows the changes to occur when both Excel and STELLA files are open simultaneously. Changes made in Excel prior to establishing the link will not change parameter values in STELLA. To overcome this problem we have built an updating macro in Excel. Run this macro by pressing Ctrl-U, Ctrl-W, Ctrl-W after you have the link between STELLA and Excel file establish to make sure all the input parameters value in STELLA model corresponds to the value in Excel.

If you working with STELLA 9, to update the linked input from Wanulcas.xls into GenRiver.stm use the "ImportData" option under the "Edit" menu. There are two types of importing data: the first one is import data “one time”, meaning the data is imported without establishing a link; the second is “persistent” data import, meaning the data is imported and a link established.

Most of the contents of Wanulcas.xls are linked to WaNuLCAS model as input parameters. Linking enable you to change input value in WaNuLCAS by changing associated values in Wanulcas.xls. The linked values are marked by blue font.

To cross-check whether input parameters were updated both in MS Excel and Stella, open a table in STELLA, tabulate input parameters and compare them with the MS Excel file.

File name

If you working with STELLA 7 or 8, the active link between the MS Excel file Wanulcas.xls and the STELLA file WaNuLCAS.stm requires that the filename for the Excel file remains the same. If you want to differentiate multiple versions of the input parameters, please make separate copies in different subdirectories (folders), otherwise the links are lost.

If you working with STELLA 9, you can give any name for the Wanulcas.xls.

You are now inside the **Main Menu** of WaNuLCAS and ready to work! In your screen you will see something like Figure App2.1.

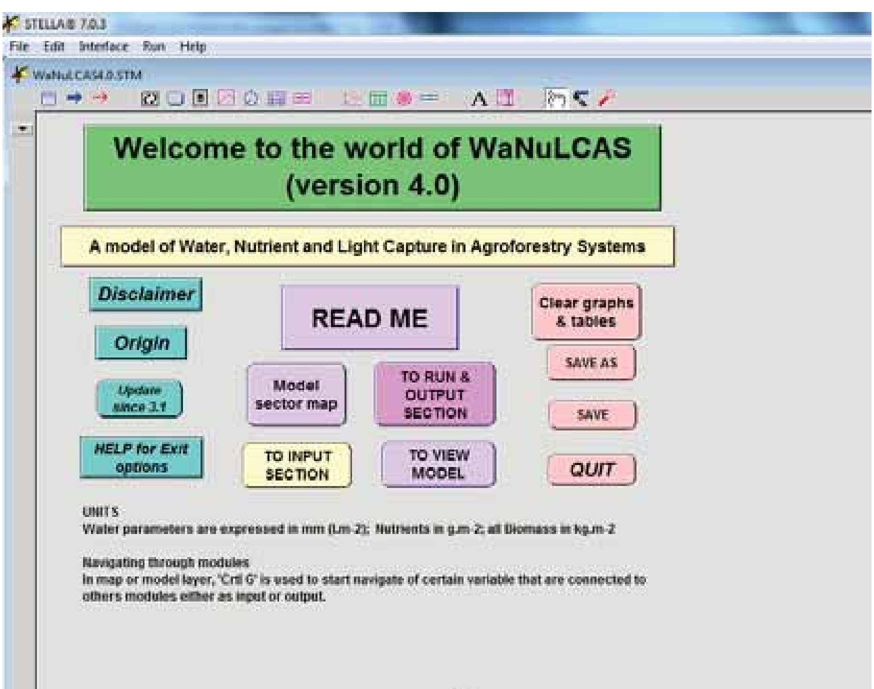


Figure App2.1. View of WaNuLCAS **Main Menu**

To familiarize yourself with WaNuLCAS we suggest you to try the following exercise:

- First, view the model then return to **Main Menu**
- Second, run the model using default parameters, then look into the simulation result
- Third, check nitrogen, phosphorus, carbon and water input-output summary of model
- Fourth, modify input parameters and try new run
- Fifth, import output resulting from new run

In the following sections you will find description on how to perform each of the suggested exercise.

To view model

This option will give you a bird's eye view of model structure: sectors, pools, flows and influences (see Figure below). Using STELLA Research you can modify the model at this level.

To return to **Main Menu** you may click on the available button or click on an arrow pointing upwards in the top left corner.

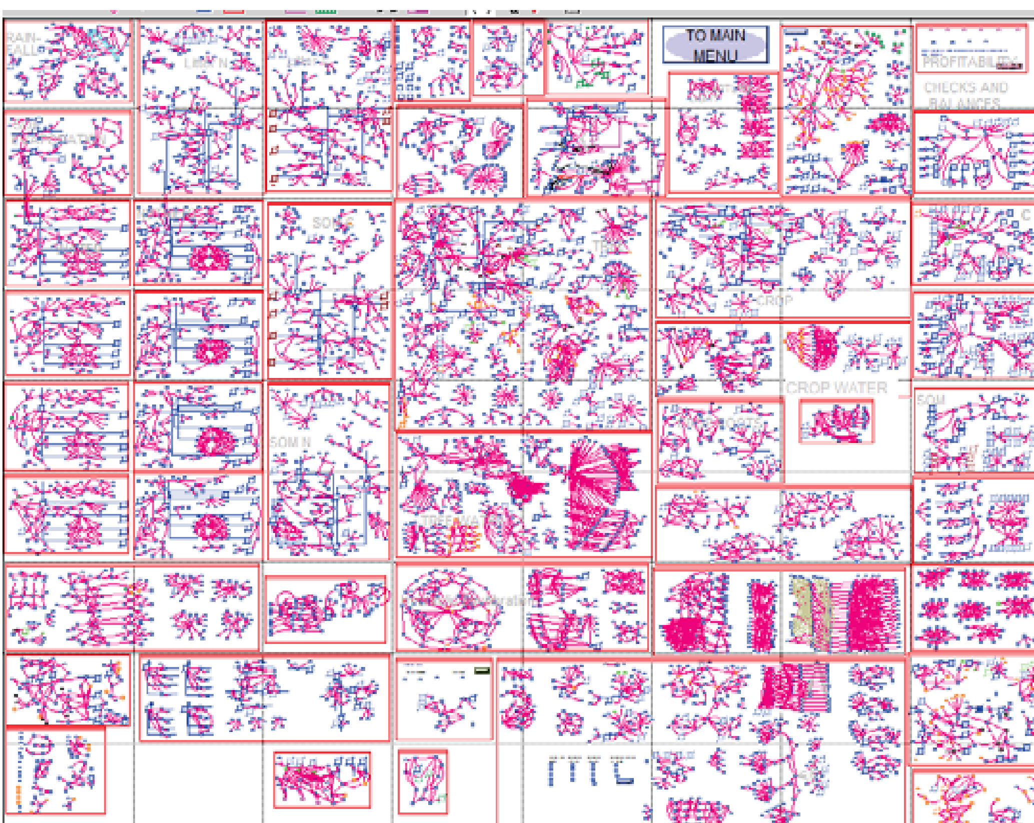


Figure App2.2. A bird's eye view of WaNuLCAS

To run and see simulations results

To run or to see simulation result from **Main Menu** click on **TO RUN AND OUTPUT SECTION** button.

Running WaNuLCAS

On the output screen you will find 5 buttons which control simulation run as listed below.

Buttons	Purpose
Run	To start simulation
Pause	To pause during simulation run
Stop	To stop simulation
Resume	To resume simulation after pausing
Time Spec	To specify length of simulation time

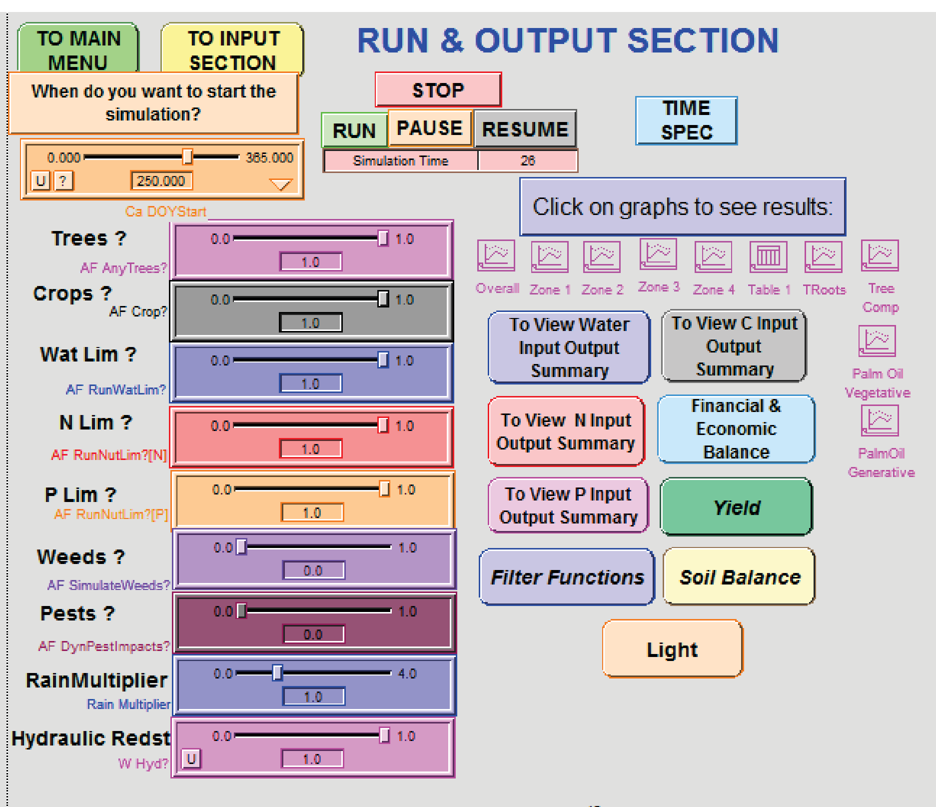


Figure App2.3. View of Output Section

Below the running control buttons, you will see a box displaying time lapsed since start of simulation (see Figure App2.3).

There are 9 sliders to simplify running different type of simulations. See Appendix 7 on acronyms to know more of the function of these sliders. The *Time Specs* screen will appear (Figure App2.4) allowing you to change beginning and ending period of simulation, also DT which is incremental time of simulation. We strongly advise you to keep DT value at 1.

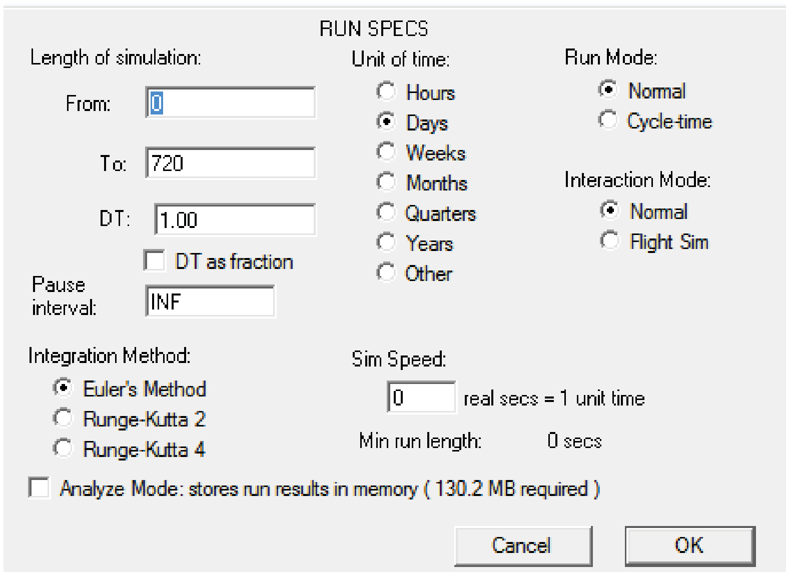


Figure App2.4. View of Time Specification screen

Seeing simulation result

There are two types of output result, (A) Graphs and (B) Tables.
To view a graph/table, click twice on the graph icon. What you will see is actually a stack of graphs/tables. To view the rest of graphs, click on the folded page at the bottom left corner.

When you look at graphs, notice that the scale on Y axis between parameters on the same graph can be different. Match the index number of parameters with index number of scales in Y axis.

Listed below is summary of available output on display. More detailed descriptions on output parameters are listed in Appendix 4 of this document.

A. Graphs

Overall : Summaries of overall zones and specific output related to Tree

Output	Content	Graph Type
Page 1	Plant biomass, tree biomass presence as total biomass	Time series
Page 2	Distribution of rainfall	Time series
Page 3	Distribution of cumulative amount of water drained out	Time series
Page 4-5	Distribution of cumulative amount of nutrient leached out	Time series
Page 6	Cumulative plant water uptake	Time series
Page 7	Total plant N & P uptake per day	Time series
Page 8-9	Amount of nutrient presence in plant aboveground biomass	Time series
Page 10	Water available, demanded and taken up by tree per day	Time series
Page 11-12	Nutrient available, demanded and taken up by tree per day	Time series
Page 13-15	Factors limiting tree growth	Time series
Page 16	C and Nutrient in SOM + litter pool	Time series
Page 17	Tree biomass and diameter	Time series
Page 18	Plant biomass, tree biomass presence as leaf and twig biomass	Time series
Page 19	Tree canopy biomass and cumulative pruned biomass	Time series
Page 20	Plant (Leaf and Twig) biomass	Histogram
Page 21	Water stock	Histogram
Page 22 - 23	Nutrient stock	Histogram
Page 24 - 25	Pore volume	Histogram

Zone 1, Zone 2, Zone 3, and Zone 4 : Each of these graphs contain similar output parameter related to zone 1, 2, 3 and 4

Output	Content
Page 1	Factors limiting crop growth
Page 2	Distribution of water stock
Page 3-4	Distribution of nutrient in soil
Page 5	Distribution of crop water uptake
Page 6	Distribution of tree water uptake
Page 7,9	Distribution of crop nutrient uptake
Page 8,10	Distribution of tree nutrient uptake
Page 11-12	Nutrient available, demanded and taken up by crop per day

OilPalms: spesific output for oilpalm

Output	Content
Page 1-3	Fruit biomass
Page 4	Biomass and oil harvested

Tree comp: spesific output related to the tree phenology

Output	Content
Page 1	Tree Leaf Area Index (LAI)

B. Tables

There is only one table containing 2 pages of water balance, plant biomass, water, N and SOM in soil.

Adding additional output parameters

To add more parameters to your tables or graphs do the following:

- Click twice on your graph/table. After a graph/table appear, click twice again on it. Now, you will see a box emerge with 2 small boxes in the upper section. The left box contains parameters that can be loaded into graph/table. The right box contains parameters already in the graph/table. A graph can contain up to 5 parameters while a table can contain more than 40 parameters.
- To load a parameter into the graph/table, highlight the parameter in **allowable** box then click an adjacent arrow pointing to the right.
- If you want to load a parameter to a new clean page, prior to the above you need to click an arrow pointing upward at the bottom left corner pointing (adjacent to **Page**). Keep on clicking until you see **NEW** as page number.

Locking graphs or tables to speed your simulation

You can lock pages in your graphs and tables that you do not need. Locked graphs or tables will not be updated in the next simulation run. This would save a lot of time needed to run the model. To lock graph or table click on the lock icon. It is in the bottom left corner of your graph or on the top right corner of your table.

Printing your output

You can print your output by clicking on printer icon. It is in the bottom left corner of your graph or on the top right corner of your table. It will ask you to specify which page of your graph or table you want to print.

Importing output results

You can save your table as a text file and your graph as a pct file. You can also use copy (Ctrl-C) and paste (Ctrl-V) your output table. For graphs you can use screen dump (Shift-Print) then paste to your favourite Microsoft software.

To view input-output summary

To view input-output summary, click on button **TO RUN & OUTPUT SECTION** in the **Main Menu**. There are 7 input-output summary you can see, Water, Nitrogen, Phosphorus, Carbon, Financial & Economic, Yield, Filter functions, Soil and Light. Choose the relevant one.
This screen gives you summary of input and output in the current system simulated. A list of parameters acronym found in this section is shown in **Appendix 4** under **Balance**.

To Modify Input Parameters

Click on button '**TO INPUT SECTION**' from **Main Menu**. It will lead you to list of input parameters.

Click again on button associated with specific parameters. Refer to Appendix 7 in Documentation Manual for more detailed information on input parameters.

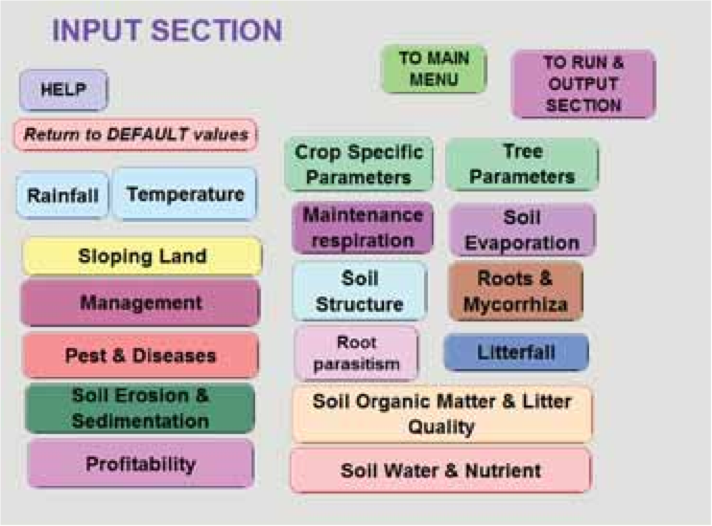


Figure App2.5. View of input menu

Basically data for WaNuLCAS model are placed in two locations, (1) the upper layer of the model and (2) Wanulcas.xls. When you click on input parameter button, it will either take to the actual input parameter location or inform you to enter it through Wanulcas.xls.

From upper layer of model there are basically three types of input device used, (1) list, (2) sliders and (3) graphical input

Changing Input Values

To modify input value just write over the current value. It will change if the new input value is within allowable range. If not, the maximum or minimum in the range will replace the value specified.

To check allowable value, please refer to Appendix 7 in documentation manual. If you experience problems, please let us know.

Please refer to **STELLA** Technical Manual to change input values on specific input device.

Description of Input on Wanulcas.xls

This Excel file is contains data used as input parameters and routines to help users in generating these input parameters. To be able to open the file you need at least Excel ver. 5.0 (MSOffice 97). The Excel must have Visual Basic Application as add-in working. The descriptions of each sheet are listed below and see Appendix 3 for more detail explanation.

All the sheets are protected by default in such a way that you will still be able to change input parameters. You can unprotect the sheets using password wanulcas (all lower case).

All input parameters in Wanulcas.xls are linked to WaNuLCAS model. For these parameters you should change it directly from the Excel sheet. For more detail description, please see Appendix 3.

Sheet	Content
READ ME	General information
Pedotransfer	Program to generate soil hydraulic properties. Output generated from this program forms data input for WaNuLCAS. These can automatically be copied to the sheet 'SOIL HYDRAULIC' where it is linked to WANuLCAS model.
Soil Hydraulic	Soil Hydraulic input parameters for each soil layer and zone. Linked to WaNuLCAS STELLA model
Phosphorus	Program to generate K_a (adsorption constant) of P, based on double Langmuir equation and related P_Bray to total mobile soil P content
Weather	Daily rainfall, daily soil temperature and daily potential evaporation
Slash and Burn	Slashing schedule and parameter impacts on the burning event
Crop Parameters/Library	Crop specific parameters
Tree Parameters/Library	Tree specific parameters
Crop Management	Planting schedule, fertilization schedule
Tree Management	Tree planting & timber harvesting schedule and pruning management.
Pedo SOM	Bulk density pedotransfer and Soil Organic Matter pedotransfer
Profitability	Input prices and labour requirement for the agroforestry system simulated and output produced.
Julian day	Information to converting calendar days per month into the 'day-of-year' (DOY) or 'Julian days' format used in the stella model
Link output	Information on how to make proper link between Wanulcas.xls and WaNuLCAS.stm and examples output that can get from WaNuLCAS simulation

To make Changes in the Model

There are 2 levels of model changes you can do; (1) change a constant parameter into a dynamic variable and (2) adding additional influencing parameter /factor to existing equations.

Changing a constant into dynamic variable

You can do this by making a constant parameter depends on existing-state variable.For example: change biomass-to-height conversion factor (Cq_HBiomConv[Cr]) into crop stage (Cq_Stage) dependent.

Adding influencing factor to existing equations

You can do this by adding additional parameter to existing equations. For example: add effect of slope as a parameter influencing potential evaporation (Evap_Pot).

Appendix 3. Description on Excel files accompanying WaNuLCAS model

The WaNuLCAS model is accompanied by 2 excel file; Wanulcas.xls and TreeParameterization.xls. Wanulcas.xls contains input parameters and routines to generate input parameters. The input parameters are linked to WaNuLCAS model. See table in Appendix 2, page 143 for short descriptions of Wanulcas.xls content. TreeParameterization.xls is developed to generate input parameters for tree. There are several other help files to assist users in generating input parameters as well as better understand WaNuLCAS model. See our web page for more information.

Wanulcas.xls

The basic purpose of this Excel file is to ease users in modifying input parameters needed to run WaNuLCAS model. Input parameters in this file are linked to the model (in the WaNuLCAS.stm file).

There are two ways to change input parameters in excel, making sure changes also occur inside the model:

1. Change input values in excel ONLY if you run the model and excel simultaneously with links established, or
2. Change input values in excel before hand then save the file. When you run the model and establish links with excel later, make sure you press Ctrl-U, Ctrl-Y or Ctrl W. This is an updating macro built within this file, that re-activates the links and sends the current parameter values of the excel file to their counterparts in stella. The macro activated by Ctrl-U will update crop and tree parameters, the Ctrl-Y will update the soil and Ctrl W will update climate parameters.

Below are comprehensive explanation of each sheet and the relevant WaNuLCAS input parameters are tabulated. Refer to Appendix 7 for definition of acronyms.

READ ME sheet.

This is the main menu of Wanulcas.xls. It contains general information and button commands to browse other sheets.

AF System sheet

This sheet stores design of the system simulated includes tree density, tree spacing, tree position within zone and zone width.

WEATHER sheet

This sheet stores daily data for 3 weather components in WaNuLCAS: Rainfall, Soil Temperature and Potential Evaporation. Default length of data and links are 1 year (365 days). These data are linked.

WaNuLCAS input parameters	Location
Rain_Data	cells C5 – C369
Temp_DailyData	cells D5 – D369
Temp_DailyPotEvap	cells E5 – E369

Pedotransfer sheet

The 'Pedotransfer' sheet contains calculation tools to help generating tables of soil hydraulic parameters. The routine is based from Wosten *et al*. (1998).

You will need to enter 5 input parameters for basic soil properties in the 'Input' section of this sheet. The pedotransfer function then estimates the parameters of a Van Genuchten equation and tabulates the relations between soil water content, hydraulic conductivity and pressure head.

The saturated hydraulic conductivity K_{sat} generated in this equation is used as a default value, representing a soil with little structure and macroporosity. The model will use the KsatInit value that you specify yourself – if it differs from the default value it is possible to simulate a gradual collapse of soil structure (with a rate governed by S_KStructDecay, set at 0.001); macroporosity can be re-created by 'Worm' activity (see Section 3.3.6).

In WaNuLCAS two definitions of 'field capacity' are used to determine the maximum soil water content one day after a rainfall event:

- Fieldcap1 = the soil water content (found in cell O11) at which downward drainage will become less then a small value K_{crit} (set in cell B36 of the input section, e.g.. 0.1 cm d^{-1}), and
- Fieldcap2 = the soil water content that is in hydrostatic equilibrium with a water table at a distance defined from the bottom of layer 4 (default distance is 0). This second value is calculated inside the STELLA model.

For the actual calculations the highest of these two values for any cell is used. The results generated by the pedotransfer routine are found in the 'Output' section of this sheet. These generated values are input parameters for WaNuLCAS model.

WaNuLCAS input parameters	Location in Excel
W_PhiTheta	cells N13 – N64
W_Ptheta	cells O13 – O64
W_PhiP (this is linked to 4 tables in the stella: W_PhiPH, W_PhiPMH, W_PhiPML, W_PhiP)	cells R13 – R64
W_ThetaPMax, W_ThetaP	cells U13 – U64
KsatDflt (default value, endpoint of loss of soil structure)	N11
Ksat (value used to initializa the model)	M11
Field Capacity1 (conductivity-limited)	O11

These input parameters need to be copied to the sheet 'Soil Hydraulic' properties. To copy the parameters for soil layer *i* and zone *j*, fill in *i* and *j* in cell N8 and N9 then click on the **COPY** button. Along with the above parameters value, input on soil texture and bulk density will be copied as well as input for Soil Organic Matter module and Soil Erosion module.

You can set up the model with the same properties for all zones and layers by repeating this for *i* = 1...4 and *j* = 1...4, modify the properties by layer or use different properties for any of the 16 cells.

Phosphorus sheet

The 'Phosphorus' sheet contains a procedure to calculate Ka_P, the apparent P adsorption constant as a function of the P concentration and P availability indices such as the P_Bray value. To run this, click on button **Psorption isotherm & Soil Database**. In this section you need to fill in the soil type for each layer of your soil in cells M8...M11. We provide default values for 9 soil types, as listed in U12....U20 If you have your own data, you can fill in parameters of a single or two-term Langmuir isotherm to describe your soil type. The parameters currently used for each soil layer are found in cells N8...R11. You also have to specify the bulk density of each layer (it is possible to use a value here that differs from the one used in the pedotransfer sheet...).

The parameters of the Langmuitr sorption isotherm are used to derive values of Ka_P for each layer, tabulated in the '**P Sorption Output**' section of the worksheet These values are linked to the WaNuLCAS.stm model.

This sheet also includes a section to initialize P in each cell (zone * layer), on the basis of indices of P availability such as the P_Bray value. To do this, you first have to specify two properties of the P availability index: the volume ratio of soil to solution used during the extraction, and the relative sorption affinity in the extraction medium (at the temperature and other conditions used). For two methods we provide these parameters P-water (compare De Willigen and Van Noordwijk, 1987) and P-Bray (with a tentative, poorly tested estimate of the relative sorption affinity of 2% of the original value).

Once the method has been thus defined, click on '**Initial P Soil**' and fill in the initial P soil indices for each cell (AD8...AG11). The values will be converted to amount of soil P in the units expected in WaNuLCAS.stm in cells (AD14...AG17). These converted values are linked to the Stella model.

WaNuLCAS input parameters	Location in Excel
Initial P in soil, N_Init*i*[P,Zone]; *i* = 1, .., 4	cells AC14 – AF17
N_KaPDef[Layer]	cells C93 – C143, E93 – E143, G93 – G143, I934 – I143

Nitrogen

This sheet store initial soil Nitrogen for each soil layer and zone.

Slash&Burn sheet

This sheet holds input parameters related to impacts of slash and burn on soil as a function of increased temperature at the soil surface. The values in this sheet is the current default values in the model, but are not linked to the model. To modify, you will need to copy the modification you have made in this sheet, to a graph converter inside the model (see from INPUT SECTION button in the model).

WaNuLCAS input parameters	Location
S&B_SurfLitBurnFrac	cells B12 – B26
S&B_NecroBurnFrac	cells C12 – C26
S&B_DeadWoodBurnFrac	cells D12 – D26
S&B_AerosolFrac	cells E12 – E26
S&B_NvolatFrac	cells F12 – F26
S&B_PvolatFrac	cells G12 – G26
S&B_SOMBurnFrac	cells J12 – J19
S&B_FirMortSeedBank	cells K12 – K19
S&B_FirIndPMobiliz	cells L12 – L19
S&B_FirImpPSorption	cells O12 – O26

CROP MANAGEMENT sheet

This sheet holds a schedule for planting crops (by zone and type) and applying N or P fertilizers. The current simulation year is defined as **YEAR 0**.

In this sheet you will be able to define the type of crop you plan to use in the simulation. In cell B2-F2 fill the letter code of crop type associated with the code in the database. It is written as options on the left hand side or see sheet **CROP LIBRARY**. The type of crop you choose here determine the parameter values copied to sheet **CROP PARAMETERS** and **PROFITABILITY**, where the values are linked to model.

You have a maximum of 5 different crop type to grow in one simulation. The letter code you fill in here will be converted to crop type value of 1 to 5, which you will use as input parameter in **column D, I, N and S**.

WaNuLCAS input parameters	Location
S&B_SurfLitBurnFrac	cells B12 – B26
S&B_NecroBurnFrac	cells C12 – C26
S&B_DeadWoodBurnFrac	cells D12 – D26
S&B_AerosolFrac	cells E12 – E26
S&B_NvolatFrac	cells F12 – F26
S&B_PvolatFrac	cells G12 – G26
S&B_SOMBurnFrac	cells J12 – J19
S&B_FirMortSeedBank	cells K12 – K19
S&B_FirIndPMobiliz	cells L12 – L19
S&B_FirImpPSorption	cells O12 – O26

CROP LIBRARY sheet

This sheet holds a database for crop specific parameters and crop related input-output for the system simulated. Overall there are 58 input parameters including 5 growth parameters as a function of crop stage. Some parameters are only required for specific settings in the simulation, e.g. there are three mutually exclusive ways of determining root length density in each cell in each time step, as governed by C_RootType.

Currently there are 10 possible type of crops in the database. For 5 of them we have provided default values, that is for crop **Cassava**, **Maize**, **Upland Rice**, **Groundnut** and **Cowpea**. If you have your own data you can fill your data values under crop type **Yours1**, ..., **Yours5**. For the whole list of input parameters stored, please refer directly to the excel sheet.

To choose the type of crop you use in simulation fill in relevant cell in sheet **CROP MANAGEMENT**.

TREE MANAGEMENT sheet

This sheet holds a schedule for tree planting, pruning and timber harvesting. As in **CROP MANAGEMENT** the current simulation year is defined as **YEAR 0**.

This where you define the type of tree you plan to use in the simulation. In cell E4-G4 fill the letter code of tree type associated with the code in the database. It is written as options on the left hand side or see sheet **TREE LIBRARY**. The type of crop you choose here determine the parameter values copied to sheet **TREE PARAMETERS** and **PROFITABILITY**, where the values are linked to model.

It is possible to grow 3 different tree type simulteneously.

WaNuLCAS input parameters	Location
T_PlantY[Tree]	cells C11 – C31, E11 – E31, G11 – G31
T_PlantDoY[Tree]	cells D11 – D31, F11 – F31, H11 – H31
T_PrunY	cells K11 – K51
T_PrunDoY	cells L11 – L51
T_PrunFracD[Tree]	cells M11 – M51, O11 – O51, Q11 – Q51
T_PrunHarvFracD[Tree]	cells N11 – N51, P11 – P51, R11 – R51
T_WoodHarvY[Tree]	cells C37 – C57, E37 – E57, G37 – G57
T_WoodHarvDoY[Tree]	cells D37 – D57, F37 – F57, H37 – H57
S&B_FirIndPMobiliz	cells L12 – L19
S&B_FirImpPSorption	cells O12 – O26

TREE PARAMETERS sheet

This sheet holds tree specific parameters. There are 95 input parameters. As in crop specific parameters, some inputs are only required if you run certain type of simulations.

All you need to fill in this sheet is the letter code of tree type (cell E8 - G9) associated with the code in the database. You have a maximum of 3 different tree type grow simultaneously in one simulation. The tree type you fill in is link to **PROFITABILITY** sheet

In the database we have so far provided only 2 default values for the trees Gliricidia sepium and Peltophorum dasyrrachis. If you have your own data you can fill in this value into the database (see cell L6). For the whole list of input parameters stored, please refer directly to the excel sheet.

PROFITABILITY sheet

The sheet contains input needed in the simulated systems and output produced. There are basically 3 categories of input, for the whole field, trees and crops. Input for the whole field you will need to fill in this sheet, while for plant input it is filled in database **TREE/CROP LIBRARY**. See directly in the excel sheet the whole list of input parameters.

Soil Hydraulic sheet

This sheet contains soil hydraulic input parameters as generated and copied from Pedotransfer sheet. The cells here are linked to the WaNuLCAS model. There are no user inputs required here, as all input is generated by the pedotransfer sheet. You can, however, check that the COPY command has lead to the expected results or not.

Pedo_SOM sheet

This sheet provide users a way to parameterize Soil Organic Matter module. This worksheet, based largely from pedotransfer equations, can be used to generate $C_{organic}$ /$C_{reference}$ value and to derive S_BDBDRefDecay value. $C_{organic}$/$C_{reference}$ is a ratio between actual $C_{organic}$ measured in the field with a reference $C_{organic}$ value for forest top soils of the same texture and pH.. This value can be used as an indicator of how soil organic matter had changed over the years at the current site. This value is an input parameter to initialize soil organic matter using Methods 2 (see Soil Organic Matter module).

S_BDBDRefDecay is parameter value indicating the rate of soil bulk density compaction over time. This changes could be due to management or soil structure degradation. The new sheet helps to calculate BDBDRef value, that is the ratio between measure soil bulk density with a reference value of bulk density at the same $C_{organic}$ content. There are two types of reference values, at agriculture soils and at forest soils (BDBDRef1 and BDBDRef2). Using these two ratio values we can have a first indication on what would be a reasonable value of S_BDBDRefDecay.

Tree parameterization.xls

This file for generate input parameters in tree library in Wanulcas.xls. Below are the detail explanation for each sheet carried out.
Main sheet, this sheet is the main menu of tree parameterization.xls which is conducted in to two parts tree survey and FBA model. Tree survey is more for estimate the tree specific

parameter while FBA model for estimate allometric branching for WaNuLCAS. It contains general information and button commands to browse tree survey and FBA model.

Survey sheet, this sheet contains 39 question that split in to 10 categories, growth stage, growth, canopy, light capture, rain interception, tree water, N fixation, N and P concentration, litterfall and litterquality. Users may answer all questions or only some of those related to the certain category.

WaNuLCAS sheet, while user answer the question on sheet survey, the input parameter for Wanulcas.xls (tree library sheet) will be automatically estimated on this sheet, later user can copy the result from this sheet to the tree library sheet.

WanFBA sheet, all input that needed to run FBA model are prepared on this sheet based on the observational data in the field. The input are needed split in to 4 categories, information of branching pattern, information of tree size, information of woody part and information of final links.

Input sheet, when user had finished fill in all the information, with 'Ctrl H' will be automatically estimated all input that needed to run the FBA model on this sheet, and 'Ctrl R' will be automatically estimated biomass allometric equation for each part (total biomass, wood, leaf and twig and litterfall). The biomass allometric equation will be automatically copied on sheet WaNuLCAS.

Sumoutput sheet, the sumoutput shows not only allometric equation but also all the important information that can be obtained from this program.

Estimate sheet, this sheet contains estimate input for WanFBA input compared to the default value.

FBA.xls

Fractal braching analysis.xls is a tool that help user to generate allometric equation of tree based on non-destructive approach using generic from Y = a D^b, Y = tree biomass and D = tree diameter.

Rainfall simulator.xls

Rainfall simulator is tool to generate daily rainfall simulator based on common 'Markov chain' way, which basically consists of two steps: i) simulating rainfall occurrence, i.e. determining whether or not a day is a rainy day or not, and ii) for rainy days, determine the amount of rainfall. A number of parameter inputs such as peakiness of the season, number of wet day, relative wet persistence, weibull value, etc is needed to generate daily rainfall using this tool. 'Help file rainfall simulator' is a file that help user to generate those input parameters. Daily or monthly rainfall data are the basis data to generate those inputs.

Appendix 4. List of Output Acronyms and Definition

No.	Acronym	Definition
1.	AF	"Agroforestry Zone" – overall design on the system
2.	B	Balance (carbon=BC, nutrient=BN, BS=Soil or water=BW)
3.	C	Crop (C = Crop, C_N = Crop Nutrient or CW = Crop Water)
4.	E	Erosion
5.	Light	Light
6.	P	Profitability (economic sector of the model)
7.	Rain	Rain
8.	T	Tree (T = Tree, T_N = Tree Nutrient or TW = Tree Water)
9.	TF	Oil palm

No.	Acronym	Definition	Units	Location
1.	AF_DepthLay1	Initial soil thickness in layer 1	m	Soil Balance
2.	BT_HarvCum[DW,Tree]	Cumulative biomass harvested from each type of tree	kg m^{-2}	Yield
3.	BC_ChangStock	Changes of current carbon stock and initial over duration of the simulation	g m^{-2}	Carbon Balance
4.	BC_CO2FromBurn	Cumulative amount of carbon released into air from burning event	g m^{-2}	Carbon Balance
5.	BC_CPhotosynth	Amount of carbon produced by crop through photosynthesis	g m^{-2}	Carbon Balance
6.	BC_CRespforFix	Amount of carbon released by crop due to respiration needed for N fixation	g m^{-2}	Carbon Balance
7.	BC_Crop	Amount of carbon currently presence as crop biomass	g m^{-2}	Carbon Balance
8.	BC_CropInit	Initial amount of carbon presence as crop biomass	g m^{-2}	Carbon Balance
9.	BC_CStockInit	Initial amount of carbon in soil organic matter and surface litter pools and tree	g m^{-2}	Carbon Balance
10.	BC_CurrentCStock	Current amount of carbon in soil organic matter, surface litter pools, tree, crop, necromass and weed	g m^{-2}	Carbon Balance
11.	BC_ExtOrgInput	Amount of carbon in external organic input eg. mulch	g m^{-2}	Carbon Balance
12.	BC_GWEffect_CO2_eq_g_per_m2	Net global warming effect in g CO_2 equivalent per m^2 over duration of the simulation	g m^{-2}	Carbon Balance
13.	BC_HarvestedC	Amount of carbon in harvested crop/yield (average over total field length)	g m^{-2}	Carbon Balance
14.	BC_HarvestedT	Amount of carbon in harvested component of tree	g m^{-2}	Carbon Balance

No.	Acronym	Definition	Units	Location
15.	BC_Inflows	Total amount of carbon entered the systems through tree and crop photosynthesis, initial tree and crop biomass and weed	g m^{-2}	Carbon Balance
16.	BC_NecromassC	Amount of carbon as necromass	g m^{-2}	Carbon Balance
17.	BC_NetBal	Balance value for carbon. It is used to check model calculation and should be (virtually) 0	g m^{-2}	Carbon Balance
18.	BC_Outflows	Current amount of carbon losses from the system through crop harvested, component of tree harvested and carbon respired	g m^{-2}	Carbon Balance
19.	BC_SOM	Current amount of carbon in soil organic matter and surface litter pools	g m^{-2}	Carbon Balance, Graph Overall (16)
20.	BC_SOMInit	Initial amount of carbon in soil organic matter and surface litter pools	g m^{-2}	Carbon Balance
21.	BC_TimeAvgCStock	Total amount of carbon in the whole system averaged over the simulation period	g m^{-2}	Carbon Balance
22.	BC_TotalRespired	Total carbon respired	g m^{-2}	Carbon Balance
23.	BC_TPhotosynth	Amount of carbon produced by tree through photosynthesis	g m^{-2}	Carbon Balance
24.	BC_Tree	Current amount of carbon in tree biomass	g m^{-2}	Carbon Balance
25.	BC_TreeInitTot	Total amount of carbon initialized as tree biomass	g m^{-2}	Carbon Balance
26.	BC_TRespforFix	Amount of carbon released by crop resulted from respiration for N fixation	g m^{-2}	Carbon Balance
27.	BC_Weed	Amount of carbon currently presence as weed	g m^{-2}	Carbon Balance
28.	BC_WeedSeeds	Amount of carbon as seeds of weed	g m^{-2}	Carbon Balance
29.	BN_CBiomInit[SlNut]	Initial amount of nutrient in crop biomass	g m^{-2}	N Balance, P Balance
30.	BN_CHarvCum[SlNut]	Amount of nutrient in harvested crop/yield (average over whole field)	g m^{-2}	N Balance, P Balance
31.	BN_CNdfaFrac	Fraction of N derived from fixation by all crop	dimensionless	Yield
32.	BN_CNFixCum	Total amount of N fixed by crop	g m^{-2}	N Balance
33.	BN_CropBiom[SlNut]	Current amount of nutrient (N or P) in crop biomass (average over total field length)	g m^{-2}	Graph Overall (8 – 9)
34.	BN_CropBiom[SlNut]	Current amount of nutrient in tree biomass	g m^{-2}	N Balance, P Balance, Graph Overall, (8 – 9)
35.	BN_CUptTot[SlNut]	Total amount of nutrient taken up by crop (average over total field length)	g m^{-2}	Graph Overall, (7)
36.	BN_EffluxTot[SlNut]	Current amount of nutrient loss from the system through crop harvested, leaching, surface run off, etc	g m^{-2}	N Balance

No.	Acronym	Definition	Units	Location
37.	BN_ExtOrgInputs[SlNut]	Total amount of nutrient entered the system from external organic input	g m^{-2}	N Balance, P Balance
38.	BN_FertCum[SlNut]	Cumulative amount of fertilizer input (average over total field length)	g m^{-2}	N Balance, P Balance
39.	BN_Immob[SlNut]	Current amount of nutrient in immobile pool	g m^{-2}	N Balance, P Balance
40.	BN_ImmPool[SlNut]	Initial amount nutrient in immobile pool	g m^{-2}	N Balance, P Balance
41.	BN_InfluxTot[SlNut]	Total amount of nutrient entered the system from initial crop biomass, fertilizer, external organic input, etc	g m^{-2}	N Balance
42.	BN_LatInCum[SlNut]	Nutrient input due to lateral flow	g m^{-2}	N Balance, P Balance
43.	BN_LatOutCum[SlNut]	Amount nutrient flows out due to lateral flow	g m^{-2}	N Balance, P Balance
44.	BN_LeachingTot[SlNut]	Total amount of nutrient leached out from bottom layers (average over total field length)	g m^{-2}	N Balance, P Balance
45.	BN_Lit[SlNut]	Current amount of nutrient in litter layer	g m^{-2}	N Balance, P Balance
46.	BN_LitInit[SlNut]	Initial amount of nutrient in litter layer	g m^{-2}	N Balance, P Balance
47.	BN_NetBal[SlNut]	Balance value for nutrient. It is used to check model calculation and should be (virtually) 0	g m^{-2}	N Balance, P Balance
48.	BN_NutVolatCum[SlNut]	Total amount of carbon volatilized from burnt necromass	g m^{-2}	N Balance, P Balance
49.	BN_SOM[SlNut]	Current amount of nutrient in soil organic matter pool	g m^{-2}	N Balance, P Balance, Graph Overall (16)
50.	BN_SOMInit[SlNut]	Initial amount of nutrient in soil organic matter pool	g m^{-2}	N Balance, P Balance
51.	BN_StockInit[SlNut]	Initial amount of nutrient (average over all zones and layers)	g m^{-2}	N Balance, P Balance
52.	BN_StockTotInit[SlNut]	Total amount of initial soil nutrient	g m^{-2}	N Balance, P Balance
53.	BN_StockTot[SlNut]	Currentl amount of nutrient in soil (average over all zones and layers)	g m^{-2}	N Balance, P Balance
54.	BN_THarvCumAll[SlNut]	Amount of nutrient in biomass harvested from tree (average over total field length)	g m^{-2}	N Balance, P Balance
55.	BN_TNdfaFrac	Fraction of N derived from fixation by tree	dimensionless	Yield
56.	BN_TNFixAmountCum	Total amount of N fixed by crop	g m^{-2}	N Balance
57.	BN_TreeInit[SlNut]	Initial amount of nutrient in tree biomass	g m^{-2}	N Balance, P Balance
58.	BN_WeedBiom[SlNut]	Current amount of nutrient in weed biomass	g m^{-2}	N Balance, P Balance
59.	BN_WeedSeedBank[SlNut]	Current amount of nutrient in seedbank	g m^{-2}	N Balance, P Balance

No.	Acronym	Definition	Units	Location
60.	BN_WeedSeedInit[SlNut]	Initial amount of nutrient in seedbank	g m^{-2}	N Balance, P Balance
61.	BS_SoilCurr	Current amount of soil	kg m^{-2}	Soil Balance
62.	BS_SoilDelta	Overall balance of input and output of soil in the model. A value of 0 means that the model calculation is in balance.	kg m^{-2}	Soil Balance
63.	BS_SoilInflowcum	Total amount of soil inflow	kg m^{-2}	Soil Balance
64.	BS_SoilInit	Initial amount of soil	kg m^{-2}	Soil Balance
65.	BS_SoilLossCum	Total amount of soil loss	kg m^{-2}	Soil Balance
66.	BW_DrainCumV	Total amount of water draining (average over all zones and layers)	l m^{-2}	Water Balance
67.	BW_EvapCum	Total amount of water evaporates from soil surface (average over all zones and layers)	l m^{-2}	Water Balance
68.	BW_LatInCum	Amount of lateral inflow (subsurface) of water	l m^{-2}	Water Balance
69.	BW_LatOutCum	Amount of lateral outflow (subsurface) of water	l m^{-2}	Water Balance, Graph Overall (3)
70.	BW_NetBal	Overall balance of input and output of water in the model. A value of 0 means that the model calculation is in balance.	l m^{-2}	Water Balance, Graph Overall (10)
71.	BW_RunOffCum	Amount of (surface) run off water	l m^{-2}	Water Balance
72.	BW_RunOnCum	Amount of (surface) run on water	l m^{-2}	Water Balance
73.	BW_StockInit	Initial total amount of water in all layers and zones of soil	l m^{-2}	Water Balance
74.	BW_StockTot	Current total amount of water in soil profile	l m^{-2}	Water Balance
75.	BW_UptCCum	Cumulative amount of water uptake by crop	l m^{-2}	Water Balance, Graph Overall (6)
76.	BW_UptTCum[Tree]	Cumulative water uptake by each tree	l m^{-2}	Water Balance Graph Overall (6)
77.	C_AgronYields[Crop]	Agronomic yield for each type of crop	kg m^{-2}	Yield
78.	C_Biom[Zone,DW]	Current crop biomass in each zone (including canopy, storage, roots)	kg m^{-2}	Graph Overall (1), Graph Zonei (1)
79.	C_BiomCan[Zone,DW]	Current crop canopy biomass in each zone	kg m^{-2}	Graph Overall (18)
80.	C_FracLim[LimFac]	Average value over the simulation for each limiting factor for crop growth, value between 0 and 1	-	Yield

No.	Acronym	Definition	Units	Location
81.	C_HydEqFluxes[Zone]	Flux of crop water by hydraulic lift	mm	Water Balance
82.	C_NDemand[Zone]	Amount of nutrient demanded by crop in each zone	kg m^{-2}	Graph Zone*i* (11 – 12)
83.	C_NPosGro[Zone,SlNut]	The effect of nutrient stress on crop growth (0=no growth, 1=no stress)	dimensionless	Graph Zonei (1)
84.	C_NUptPot[Zone]	Amount of nutrient available for crop uptake in each zone	g m^{-2}	Graph Zonei (11 – 12)
85.	C_NUptTot[Zone]	Amount of nutrient uptake by crop in each zone	g m^{-2} day^{-1}	Graph Zonei (11 – 12)
86.	Cent_BalTotal[SlNut]	Overall balance of input and output in minera¬lization module (adapted from CENTURY model). A value of 0 means that model calculations are in balance	g m^{-2}	N Balance, P Balance
87.	CW_PosGro[Zone]	The effect of water stress on crop growth in each zone (0=no growth, 1=no stress)	dimensionless	Graph Zone*i* (1)
88.	E_TopSoilDepthAct[Zone]	Current soil thickness in layer 1	m	Soil Balance
89.	GHG_CumCH4Emission	Cumulative emission of CH_4	g m^{-2}	N Balance
90.	GHG_GWP_N2O&CH4	Global Warming Potential of the systems based on the emmsion of CH_4 and NO_2. It is expressed relative to CO_2	-	N Balance
91.	GHG_N2_Fraction	Fraction of N_2 emission	dimensionless	N Balance
92.	GHG_NO_Fraction	Fraction of NO emission	dimensionless	N Balance
93.	GHG_N2O_Fraction	Fraction of N_2O emission	dimensionless	N Balance
94.	Light_CRelCap[Zone]	Relative light capture by crop (on scale 0-1)	g m^{-2}	Graph Zone*i* (1)
95.	Light_CRelSupply[Zone]	Potential crop growth limited by light capture relative to the potential without presence of trees (1 = no limitation, 0 = no growth)	-	Light
96.	N_CumAtmInput[SlNut]	Amount of nutrient derived from atmospheric deposition	g m^{-2}	N Balance, P Balance
97.	N_CUpti[Zone,SlNut]	Amount of nutrient uptake by crop from i-th soil layer of each zone per day	g m^{-2} day^{-1}	Graph Zone*i* (7, 9)
98.	N_EdgeFFH[SlNut]	A value describing filter function horizontally at the edge of plot	dimensionless	Filter Function
99.	N_EdgeFFV[SlNut]	A value describing filter function vertically at the edge of plot	dimensionless	Filter Function
100.	N_LeachCumV[Zone,SlNut]	Total amount of nutrient leached out from bottom layer of each zone	g m^{-2}	Graph Overall (4 – 5)
101.	N_Leachi[Zone,SlNut]	Amount of nutrient leached out from i-th layer of each zone	g m^{-2}	Graph Zone*i* (13 – 14)
102.	N_LocFF3i[SlNut]	A value describing filter function in the 3rd layer of soil	dimensionless	Filter Function
103.	N_Stocki[Zone,SlNut]	Amount of nutrient stock in each zone of layer *i*	g m^{-2}	Graph Zone*i*(3, 4)

No.	Acronym	Definition	Units	Location
104.	N_TotFFTot[SlNut]	A value describing how the whole system function as a filter. Filter function defined as nutrient taken up by plant divided by total nutrient taken up and loss	dimensionless	Filter Function
105.	N_TUpti[Zone,SlNut]	Amount of nutrient taken up by tree from *i*-th soil layer of each zone per day	g m^{-2} day^{-1}	Graph Zone*i* (8, 10)
106.	P_CCostAvg[Price]	Average cost of crop management	currency unit ha^{-1}	Economic & Financial Balance
107.	P_CReturnAvg[Price]	Amount of money contributed from crop production	currency unit ha^{-1}	Economic & Financial Balance, Yield
108.	P_CumLabUse	Total amount of labour use to manage the system	man days	Yield
109.	P_GeneralCost[Price]	Total cost needed to maintain the system	currency unit ha^{-1}	Economic & Financial Balance
110.	P_NPV[Price]	Net present value of the system	currency unit ha^{-1}	Economic and Financial Balance
111.	P_TCostTot[Price]	Total cost of crop management	currency unit ha^{-1}	Economic and Financial Balance
112.	P_TReturn[Price]	Amount of money contributed from tree production	currency unit ha^{-1}	Yield
113.	P_TReturnTot[Price]	Total amount of money contributed from tree production	currency unit ha^{-1}	Economic and Financial Balance, Yield
114.	Rain	Amount of rain per day	l m^{-2} day^{-1}	Graph Overall (2)
115.	Rain_Cum	Cumulative amount of rainfall	l m^{-2}	Water Balance, Table 1 (1)
116.	Rain_In[Zone]	Actual amount of rain going into each zone	l m^{-2} day^{-1}	Graph Overall (2), Table 1 (1)
117.	Rain_IntercEvapCum	Amount of water evaporated from intercepted water	l m^{-2}	Water Balance
118.	T_Biom[Tree]	Current amount of biomass for each tree (above and belowground)	kg m^{-2}	Graph Overall (1)
119.	T_BiomCumTot	Total cumulative amount of tree biomass (including litterfall, rootdecay, harvested pruning)	kg m^{-2}	Yield
120.	T_CumLatexHarv[Tree]	Total latex harvested	kg m^{-2}	Yield
121.	T_FracLim[Tree,LimFrac]	Average value over the simulation for each limiting factor for tree growth, value between 0 and 1	dimensionless	Yield

No.	Acronym	Definition	Units	Location
122.	T_FruitHarvCum[Tree]	Total fruit harvested	kg m^{-2}	Yield
123.	T_GroRes[Tree]	Current amount of biomass in tree growth reserves	kg m^{-2}	Graph Overall (17)
124.	T_HydEqFluxes[Tree]	Flux of tree water by hydraulic lift	mm	Water Balance
125.	T_LAI[Tree]	Tree Leaf Area Index	dimensionless	Graph Tree Comp
126.	T_LfTwig[Tree]	Current amount of biomass in tree canopy	kg m^{-2}	Graph Overall (17, 18, 19)
127.	T_Light[Tree]	Fraction of light received by tree	dimensionless	Graph Overall (13 – 15)
128.	T_NBiom[SlNut,Tree]	Current amount of nutrient in tree aboveground biomass	g m^{-2}	N Balance, P Balance, Graph Overall (8 – 9)
129.	T_NDemandAll[SlNut]	Amount of nutrient demanded by tree per day	g m^{-2} day^{-1}	Graph Overall (11 – 12)
130.	T_NfixCum[SlNut,Tree]	Cumulative amount of nutrient derived from fixation by tree	g m^{-2}	N Balance
131.	T_NPosgro[SlNut]	The effect of nutrient stress on tree growth (0=no growth, 1=no stress)	dimensionless	Graph Overall (13 – 15)
132.	T_NUptPotAll[SlNut]	Total amount of nutrient in all soil layers available for tree per day	g m^{-2} day^{-1}	Graph Overall (11 – 12)
133.	T_NUptTotAll[SlNut]	Total amount of nutrient taken up by tree (average over total field length)	g m^{-2} day^{-1}	Graph Overall (7,11 – 12)
134.	T_Root[Tree]	Current amount of tree root biomass	kg m^{-2}	Graph Overall (17)
135.	T_StemDMax	Stem diameter of tree	m	Graph Overall (17)
136.	T_Wood	Current wood/stem biomass	kg m^{-2}	Graph Overall (17)
137.	T_WoodHarvCum[Tree]	Total timber/wood harvested	kg m^{-2}	Yield
138.	TF_BunchWeight[Tree,FruitBunch]	Total weight of oil palm fruit per fruit stages	kg m^{-2}	Graph OilPalm
139.	TF_CumFruitHarv[Tree]	Cumulative amount of oil palm fruit harvested	kg m^{-2}	Graph OilPalm
140.	TF_CumOilHarvest[Tree]	Cumulative amount of oil harvested	kg m^{-2}	Graph OilPalm
141.	TF_FemBunchFrac[Tree]	Fraction of female flowers/fruit	kg m^{-2}	Graph OilPalm
142.	TF_ FruitperBunch[Tree,FruitBunch]	Number of oil palm fruit per fruit stages	kg m^{-2}	Graph OilPalm

No.	Acronym	Definition	Units	Location
143.	TF_WatNutSuff[Tree]	The effect of water and nutrient stress on the oilpalm growth	dimensionless	Graph OilPalm
144.	TW_DemandActAll	Amount of water demanded by all tree per day	$l\ m^{-2}\ day^{-1}$	Graph Overall (10)
145.	TW_Posgro[Tree]	The effect of water stress on tree growth (0=no growth, 1=no stress)	dimensionless	Graph Overall (10, 13 – 15)
146.	TW_UptPotAll	Total amount of water in all soil layers available for tree per day	$l\ m^{-2}\ day^{-1}$	Graph Overall (10)
147.	TW_UptTotAll	Current amount of water uptake by tree from all soil layers per day	$l\ m^{-2}\ day^{-1}$	Graph Overall (10)
148.	W_CUpti[Zone]	Amount of water taken up by crop from i-th soil layer of each zone per day	$l\ m^{-2}\ day^{-1}$	Graph Zonei (5)
149.	W_DrainCumV[Zone]	Cumulative amount of water drained out from bottom layer	$l\ m^{-2}$	Graph Overall (3)
150.	W_Stocki[Zone]	Amount of water each zone in i-th soil layer	$l\ m^{-2}$	Graph Zonei (2)
151.	W_TUpti[Zone]	Amount of water taken up by all tree from i-th soil layer of each zone per day	$l\ m^{-2}\ day^{-1}$	Graph Zonei (6)

Appendix 5.Deriving uptake equation (P. de Willigen)

According to De Willigen and Van Noordwijk (1987 - Table 9.1, equ. 12.9) uptake rate is given by:

$$\frac{\rho^2 \Theta \beta}{2\phi\eta} = \frac{(\rho^2 - 1)\bar{c}}{2G(\rho)} \quad \text{[A1]}$$

Now (l.c. page 125):

$$G(\rho) = \frac{1}{2}\left\{\frac{1-3\rho^2}{4} + \frac{\rho^4 \ln\rho}{\rho^2 - 1}\right\} \quad \text{[A2]}$$

As normally $\rho \ll 1$

$$G(\rho) \approx \rho^2 \left(-\frac{3}{8} + \frac{1}{2}\ln\rho\right) \quad \text{[A3]}$$

The parameters ρ1, ϕ2 and η3 are given by:

$$\rho = \frac{R_1}{R_0} \quad 1$$

$$\phi = \frac{D \quad S_i}{U R_0} = \frac{D\theta\beta C_i}{U R_0} \quad 2 \qquad \text{[A4]}$$

$$\eta = \frac{H}{R_0} \quad 3$$

and the dimensionless concentration by:

$$\bar{c} = \frac{C}{C_i} \quad \text{[A5]}$$

where D is the diffusion coefficient ($m^2.d^{-1}$), H is the thickness of the soil layer (m), *U* is the uptake rate ($g.m^{-2}.d^{-1}$), R_0 the radius of the root (m) and R_1 the radius of the soil cylinder surrounding the root. The latter is given by:

$$R_1 = \frac{1}{\sqrt{\pi L_{rv}}} \quad \text{[A6]}$$

The parameter 4 denotes the buffer power of the soil. Substitution of (A2)-(A6) into (A1) leads to:

$$U = \frac{D\bar{C}H}{R_1^2\left(-\frac{3}{8} + \frac{1}{2}\ln\rho\right)} \quad \text{[A7]}$$

The diffusion coefficient is a function of the water content Θ 5, according to:

$$D = (a_1\Theta + a_0)\,\Theta\, D_0 \qquad \textbf{[A8]}$$

where D_0 is the diffusion coefficient of the nutrient in question in water, whereas the concentration can be calculated from the amount in the layer N_{stock} (g.m^{-2}):

$$C = \frac{N_{stock}}{K_a + \Theta} \qquad \textbf{[A9]}$$

K_a being the adsorption constant. Substitution of (A2)-(A9) into (A1) ultimately yields (A10) which is the basis for equation (10) in WaNuLCAS.

$$U = \frac{\pi D_0\,(a_1\Theta + a_0)\,\Theta\, H\, N_{stock}}{(K_a + \Theta)\left[-\frac{3}{8} + \frac{1}{2}\ln\left\{\frac{1}{R_0\sqrt{\pi L_{rv}}}\right\}\right]} \qquad \textbf{[A10]}$$

Appendix 6. Trouble-shooting and Tips

As for any complex system, the number of ways in which the model can go wrong is nearly infinite, while there is only one (or a few) ways it can go right., So the odds certainly are against us. If things go wrong, however, there are a number of ways to identify the source of the errors as a step towards mending it.

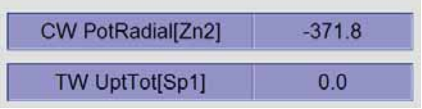
Difficulties in loading the files:

- **Links can not be established**: check whether you have indeed opened the right XLS file and have not changed the position of any of the linked parameters by adding or deleting rows or columns or moving cell contents around,
- **Low Memory ('cannot continue DDE conversation')**; it may help to remove all memory demanding programs, including net-work links and microsoft office toolbars from the memory; sometimes it helps to re-boot the computer and start afresh; this type of error message may occur when you update the links by running the Ctrl+Y, Ctrl+W or Ctrl+U macro in the excel; if the problem persists you'll have to get more RAM on your computer (32 MB is a bare minimum); you can also make runs in the Stella model without opening the excel + links, or close the excel file after updating parameter values, to increase the memory allocation for the Stella model.
- **Running speed** can be increased by locking graphs/tables that you're not currently interested in.
- **Links are not working**; Wanulcas.xls is developed using MS Excel with English language as the settings. If you use MS Excel with settings on other languages the link will not work. This is because the links will use different language term. As an example: in English language setting, position of a cell is referred to as R (Row) and C (Column)olumn. In Portuguesse, it is referred to as L (Lina) and C (Colom). Similarly, in French it refer to as L and C. If you are working using STELLA version 6 or above,   you can modify the links directly within the model (WaNuLCAS.stm) using Link Editor option. If you are working with Stella version 5, you will need to update the links again.

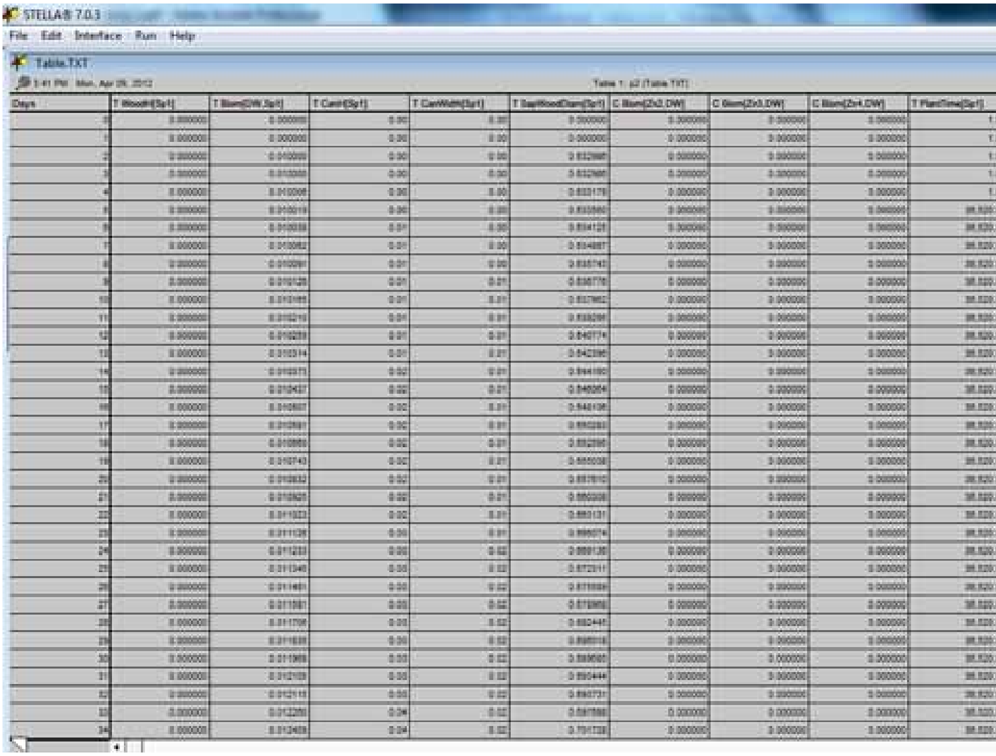
Error message at start or during RUN

It is possible that when you press RUN you get an error message, in stead of output. The message will indicate a parameter name and the error usually consists of division by zero. We have tried to protect all equations from such an event, but if necessary you can add an 'If *** <> 0 then '...existing equation...' else 0' statement to the equation involved, with the *** replaced by any divisor in the equation.

The current value of all parameters and variables at the time of the crash can be viewed by inserting a numeric display output as a step towards identifying what goes wrong. Below is an example.



If the RUN actually starts, a Table can be used to view more then one parameter at a time, and check its changes with time.



A second class of error is that trees or crops do not grow as expected, or trees or crops do not grow at all

A second class of error is that trees or crops do not grow as expected, or other events do not happen as you though you asked for in the calendar. In such case you can add a new table to the output screen and check where the error originates by tabulating output values related to the event. For trees and crops it is helpful to tabulate the growth stage as well as components of the biomass, to check whether the error is in the plants not getting started at all, or not making biomass. It may be necessary to tabulate input values and compare with the values you intended.

Sometimes the x-axis for tabulated input parameters, such as the strings of crop or tree parameter, gets changed and all parameter values are shifted by one or more positions, leading to nonsensical results; if this happens open the graph and re-adjust the number of points.

You can try the 'return to default' button on the 'input' screen to restore (unintentional) modifications of parameter settings that may be responsible for unexpected run results; if you want to modify the 'default' values to which you return with this button, you have to modify the values in the dialogue boxes on the 'second level' (the modeling layer))

Appendix 7.Input parameters and their definition

Abbreviations used in parameter names

No	Acronym	Definition	No	Acronym	Definition
1.	AF	"Agroforestry Zone" – overall design of the system	14.	Mn	Nutrients in Litter Layer
2.	C	Crop (C = Crop, C_N = Crop Nutrient or CW = Crop Water)	15.	Mn2	Nutrients in Soil Organic Matter (SOM)
3.	Ca	Crop Calendar (schedule)	16.	N	Nutrient (currently including N and P)
4.	Cent	Input Output Summary for Litter (based on Century Model)	17.	P	Profitability (economic sector of the model)
5.	Cent2	Input Output Summary for SOM (based on Century Model)	18.	PD	Pest and Disease
6.	Cq	Crop Sequence (crop parameters)	19.	Rain	Rain
7.	E	Erosion	20.	Rt	Root
8.	Evap	Evaporation	21.	S&B	Slash and Burn
9.	G	Grazing	22.	S	Soil Structure
10.	LF	Lateral Flow	23.	T	Tree (T=Tree, T_N=Tree Nutrient or TW=Tree Water)
11.	Light	Light	24.	TF	Tree Fruit (oil Palm Module)
12.	Mc	Carbon in Litter Layer	25.	Temp	Temperature
13.	Mc2	Carbon in Soil Organic Matter (SOM)	26.	W	Water

Note: Without green dot are CORE modules, with '•' (green dot) in front means ADDITIONAL modules

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
1.	AF_AnyTrees?	Parameter governing an option to simulate system with trees. Value 0 means system without trees, value 1 means system with trees is possible	dimensionless	0 or 1 (1)	RUN & OUTPUT SEC-TION
2.	AF_Circ?	Switch to decide on circular versus linear symmetry. 1 = circular system, 0 =linear system	dimensionless	0 or 1 (0)	(AF System)
3.	AF_Crop?	Parameter governing an option to simulate system with crop. Value 0 means system without crop, value 1 means system with crop	dimensionless	0 or 1 (0)	RUN & OUTPUT SEC-TION
4.	AF_DeepSubSoil	Equivalent depth of the subsoil below layer 4, that is used to calculate the effective water outflow from the soil column, via S_KsatVDeepSub	m	0 - 10 (3)	Agroforestry Zone
5.	AF_DepthDynamic?	Swicth for making the depth of soil layer 1 on sloping land system a dynamic property	dimensionless	0 or 1 (0)	Agroforestry Zone/Sloping Land and Parkland System
6.	AF_DepthGroundWater Table	Depth of groundwater table below the bottom of layer 4, expressed in m. For the time being the value is used as a constant in defining 'field capacity'.	m	0 – 10 (0)	Agroforestry Zone
7.	AF_DepthLayi[Zone]	Soil depth increment in (= layer thickness of) *i*-th soil layer, *i* = 1, 2, 3, 4. For sloping land systems the value for the layer 1 is used as average topsoil depth at the start of the run; actual depth of layer 1 will be calculated from the two AF_Slope parameters	m	0 - 1 (.05, .15, .3, .5 for i = 1,..,4)	(AF System)
8.	AF_DynPestImpacts?	Switch governing an option to simulate system with dynamic pest impact. Value 0 means no dynamic pest impacts, value 1 means dynamic pest impacts is possible.	dimensionless	0 – 1 (0)	RUN & OUTPUT SEC-TION
9.	AF_PlotNumberUphill	Number of similar uphill plot neighbors as source of Lateral Inflow & Run-on	dimensionless	(0)	Agroforestry zone
10.	AF_RunNutLim[SoilNut]?	Switch governing an option to simulate system with nutrient limitation. Value 0 means no nutrient limitation, value 1 means nutrient is possible.	dimensionless	0 – 1 (1)	RUN & OUTPUT SEC-TION
11.	AF_RunOnFrac	Fraction of surface runoff from the area uphill that enters the simulation area as run-on.	dimensionless	0 – 1 (0)	Agroforestry Zone
12.	AF_RunWatLim?	Parameter governing an option to simulate system with water limitation. Value 0 means no water limitation, value 1 means water limitation is possible.	dimensionless	0 – 1 (1)	RUN & OUTPUT SEC-TION

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
13.	AF_SimulateWeeds?	Parameter governing an option to simulate weed growth. Value 0 means no weed growth, value 1 means weed will start growing whenever crop is absent.	%	0 or 1 (0)	RUN & OUTPUT SECTION
14.	AF_SlopeSurfInit	Slope (expressed as percent elevation increment per horizontal distance) of the soil surface at the start of the simulation; this value can differ from the slope of the soil profile AF_SlopeSoilHoriz, but should not differ too much.	%	0 – 100 (0)	Agroforestry Zone/Sloping Land and Parkland System
15.	AF_SlopeSoilHoriz	Slope (expressed as percent elevation increment per horizontal distance) of the soil horizons below the surface, especially that of the topsoil, used to calculate actual topsoil depth per zone.	%	0 – 100 (0)	Agroforestry Zone/Sloping Land and Parkland System
16.	AF_StoneFrac[Zone,SoilLayer]	Fraction of stone in each soil layer and zone	dimensionless	0 – 1 (0)	Agroforestry Zone
17.	AF_TreePosit[Tree]	Position of each tree type. It can be in zone 1 (1) or zone 4 (4); if one wants it to be in both, two otherwise equal tree types can be defined.	dimensionless	1 or 4 (1)	(AF System)
18.	AF_WeedZn?[Zone]	Switch 0 or 1 to have weeding application for each zone (1 = weeding application, 0 = no weeding)	dimensionless	0 or 1 (0)	Management/Weed Growth
19.	AF_Zone[Zone]	Width of each zone. Width of zone 4 is calculated back from AF_ZoneTot minus the sum of zone 1+2+3	m	0 – 100 (.5, 1,1)	(AF System)
20.	AF_ZoneTot	Total width of agroforestry system simulated	m	0 – 100 (3.5)	(AF System)
21.	C_AgronYMoistFrac[Cr]	Standard moisture content for expressing marketable yields of each crop	dimensionless	0 – 1 (.15)	(Crop Library)
22.	C_ApplyMaintResp?	On/Off switch for applying the maintenance respiration,;1 = on, 0 =off	dimensionless	0 or 1 (0)	Maintenance Respiration
23.	C_DailyWeedSeedDecayFrac	Fraction of the weed seed bank that looses viability and is transferred to the litter pool for decomposition	fraction day^{-1}	0 – 1 (.02)	Management/Weed Growth
24.	C_HostEffForT1[Cr]	Effectiveness of crop roots as host for a parasitic tree (T1)	$cm^3\ cm^{-1}$	(0)	Root Parasitism
25.	C_RelRespGroRes	Relative weighting factor for growth used in calculating daily maintenance respiration	dimensionless	(.5)	Maintenance Respiration
26.	C_RelRespRt	Relative weighting factor for roots used in calculating daily maintenance respiration	dimensionless	(.3)	Maintenance Respiration
27.	C_RelRespStLv	Relative weighting factor for stem & leaves used in calculating daily maintenance respiration	dimensionless	(.5)	Maintenance Respiration

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
28.	C_RelRespYieldCurr	Relative weighting factor for developing fruits/Yield as part of total biomass as used for maintenance respiration	dimensionless	(1)	Maintenance Respiration
29.	C_ResidRemovalFrac	Fraction of crop residue removed from field (not returned as mulch). The same value applies for all zones and all crops used in the simulation	fraction	0 – 1 (0)	Management/Mulching
30.	C_RespperBiom	The relative use of resources for maintenance respiration per unit biomass	dimensionless	0 – 0.2 (.05)	Maintenance Respiration
31.	C_RespTemp	A graphical relation between temperature and maintenance respiration	dimensionless	(see C_RespTemp graph)	Maintenance Respiration
32.	C_Tmin	Minimum Air Temperature for Crop	0 Celsius	20	Temperature
33.	C_TOpt	Optimum Air Temperature for Crop	0 Celsius	21	Temperature
34.	C_WeedGermFrac	Fraction of weed seeds in the seed bank that germinates when a new opportunity arises, e.g. at the end of a cropping season	fraction	0 –1 (.1)	Management/Weed Growth
35.	C_WeedSeedBankInit	Initial dry weight of weed seeds in seed bank	kg m^{-2}	0 –1 (.01)	Management/Weed Growth
36.	C_WeedSeedExtInflux	Daily influx of weed seeds from outside of the plot	kg m^{-2} day^{-1}	0 – 0.1 (.00001)	Management/Weed Growth
37.	Ca_CType[Zone]	A graphical input parameter governing the type of crop planted in sequence, with the possibility of having different crops (and/or planting times) in different zones. Associated with type of crop in database. See Wanulcas.xls	dimensionless	1 – 5 (2)	(Crop Management)
38.	Ca_DoYStart	Day of year at which simulation starts	julian days	1 – 365 (300)	RUN & OUTPUT SECTION
39.	Ca_ExtOrgApp?[Type]	Parameter governing an option to have simulation with applying external organic input or not. Value 0 means not applying external organic input, value 1 means applying external organic input	dimensionless	0 or 1 (0)	(Crop Management)
40.	Ca_FertApp?[SiNut]	Parameter governing an option to have simulation with applying fertilizer or not. Value 0 means not applying fertilizer, value 1 means applying fertilizer	dimensionless	0 or 1 (1)	(Crop Management)
41.	Ca_FertOrExtOrgAppAmount[Zone]	Amount of N or P fertilizer or external organic applied. A graphical input parameter.	g m^{-2}	0 – 10 (4.5 for each N and P)	(Crop Management)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
42.	Ca_ FertOrExtOrgAppDoY[SiNut]	Time of fertilizer or external organic input application. A graphical input parameter.	julian days	1 – 365 (see excel sheet Crop Management)	(Crop Management)
43.	Ca_ FertOrExtOrgAppYear[SiNut]	Year of fertilizer or external organic input application. A graphical input parameter.	dimensionless	any integer value (see excel sheet Crop Management)	(Crop Management)
44.	Ca_ImmAmount[P,Zone]	Amount of immobile P fertilizer applied. A graphical input parameter	g m^{-2}	(see Ca_ImmAmount graph)	Management/P Immobile Input
45.	Ca_ImmDOY[P]	Time of immobile P fertilizer application. A graphical input parameter	julian days	1 – 365 (see Ca_ImmDOY graph)	Management/P Immobile Input
46.	Ca_ImmY[P]	Year of immobile P fertilizer application. A graphical input parameter	dimensionless	Any integer value (see Ca_ImmY graph)	Management/P Immobile Input
47.	Ca_PlantDoY[Zone]	Day of crop planting for each subsequent crop. A graphical input parameter.	julian days	1 – 365 (see excel sheet Crop Management)	(Crop Management)
48.	Ca_PlantYear[Zone]	Year of planting for each subsequent crop. A graphical input parameter	dimensionless	any integer value (see excel sheet Crop Management)	(Crop Management)
49.	Cq_CHarvAlloc[Cr]	Allocation of biomass to harvested parts (grain, tuber) as a function of crop growth stage.	dimensionless	(see Cq_CHarvAlloc table)	(Crop Library)
50.	Cq_ClosedCan[Cr]	Amount of crop canopy biomass at which canopy is closed and nutrient demand per unit new biomass shifts from Cq_ConcYoung to Cq_ConcOld.	kg m^{-2}	0 – 0.5 (0.2)	(Crop Library/Nutrient Uptake)
51.	Cq_CLWR[Cr]	Crop leaf weight ratio = gram of green leaf area per gram of shoot, for each crop species as a function of crop growth stage.	g m^{-2}	(see Cq_CLWR table)	(Crop Library)
52.	Cq_ConcOld[Cr,SiNut]	Nutrient concentration in crop tissue formed after biomass has reached the Cq_ClosedCan value.	dimensionless	0 – 0.1 (N = .01, P = .0025	(Crop Library/Nutrient Uptake)
53.	Cq_ConcRt[Cr]	N concentration in crop roots	dimensionless	0 – 0.1 (.01)	(Crop Library/Nutrient Uptake)
54.	Cq_ConcYoung[Cr,SINut]	Nutrient concentration in young crop biomass (before biomass has reached the Cq_ClosedCan value).	dimensionless	0– 0.1 (N = .015 P = .007)	(Crop Library/Nutrient Uptake)
55.	Cq_CovEff[Cr]	Crop Cover Efficiency factor, used in calculating erosion (Erosion type 1)	dimensionless	0 – 1 (1)	(Crop Library/Soil Erosion)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
56.	Cq_CRelLUE[Cr]	Relative light use efficiency (fraction of Cq_GroMax achieved per unit light capture) for each type of crop grown as a function of crop growth stage.	dimensionless	(see Cq_CRel-LUE table)	(Crop Library)
57.	Cq_DOYFlwBeg[Cr]	The earliest day in a year when crop start to flowers	julian days	1 – 365 (1)	(Crop Library/Annual or Perennial?)
58.	Cq_DOYFlwEnd[Cr]	The latest day in a year when crop start to flowers	julian days	1 – 365 (365)	(Crop Library/Annual or Perennial?)
59.	Cq_GroMax[Cr]	Maximum daily dry matter production rate at full light capture, for each crop species under local conditions	kg m^{-2} day^{-1}	0.001 – 0.1 (.014)	(Crop Library/Crop Growth)
60.	Cq_Gseed[Cr]	Seed weight (initial C_CarbHydrReserves to be used for growth).	kg m^{-2}	0.001 – 0.1 (.004)	(Crop Library/Crop Growth)
61.	Cq_HBiomConv[Cr]	Factor for conversion of crop biomass increment (up to crop stage 1) to crop height increment	dimensionless	0.1 – 10 (7)	(Crop Library/Crop Growth)
62.	Cq_kLight[Cr]	Light extinction coefficient for the crop canopy = efficiency of crop foliage in absorbing light.	dimensionless	0 – 1 (.65)	(Crop Library/Light Capture)
63.	Cq_LAIMax	Maximum leaf area index for the crop; if more biomass is produced a proportional amount is transferred to the litter layer	dimensionless	(5)	(Crop Library/Canopy)
64.	Cq_LignResid[Cr]	Lignin concentration of crop residue (eg. 20%=0.2).	dimensionless	0 – 1 (.2)	(Crop Library/Litter Quality)
65.	Cq_LignRootRes[Cr]	Lignin concentration of crop root residues	dimensionless	0 – 1 (.2)	(Crop Library/Litter Quality)
66.	Cq_Lp[Cr]	Hydraulic conductivity of crop roots, reflecting the physiological entry resistance to water per unit root length and unit gradient.	cm day^{-1}	0 – 0.00001 (.00001)	(Crop Library/Water Uptake)
67.	Cq_MaxRemob[Cr]	Maximum proportion of stem and leaves remobilized per day to the CarbHydrReserves pool, from which it can, for example, be used for growth of the storage component (grain, tuber)	day^{-1}	0 – 0.1 (.05)	(Crop Library/Crop Growth)
68.	Cq_MycMaxInf[Cr]	Fraction of crop roots infected by mycorrhiza for a soil layer where the Rt_MTInfFrac parameter is 1	dimensionless	0 – 1 (.25)	(Crop Library/ Mycorrhiza Fraction)
69.	Cq_NFixDayFrac[Cr]	Fraction of current N deficit derived from atmospheric N_2 fixation per day for each crop type, if Cq_NFixVariable = 0 ('false').	day^{-1}	0 – 1 (0)	(Crop Library/N Fixation)
70.	Cq_NFixDWMaxFrac[Cr]	Maximum fraction of the C_GroRes[Dw] pool that can be respired for N_2 fixation if Cq_NFixVariable = 0 ('false')	day^{-1}	0 – 0.5 (.1)	(Crop Library/N Fixation)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
71.	Cq_NFixDWUnitCost[Cr]	Dry weight cost for respiration per unit N_2 fixation, if Cq_NFixVariable = 0 ('false')	kg [dw] g^{-1} [N]	0 – 1 (.01)	(Crop Library/N Fixation)
72.	Cq_NFixResp[Cr]	Responsiveness of N_2 fixation to N stress (N in biomass divided by N target), if Cq_NFixVariable = 0 ('false')	dimensionless	0 – 5 (1)	(Crop Library/N Fixation)
73.	Cq_NFixVariable?[Cr]	Switch (0 = false, 1 = true) to choose between variable (N-stress dependent) versus constant N_2 fixation as fraction of N deficit	dimensionless	0 or 1 (0)	(Crop Library/N Fixation)
74.	Cq_NutMobC[Cr,SiNut]	Relative rate of transfer, per unit root length density (cm cm^{-3}), from the 'immobile' pool of nutrients to the 'mobile' or sorbed pool, due to Crop root activity	m^2 day^{-1}	0 – 0.02 (0)	Crop Library/Crop effect on nutrient mobility
75.	Cq_PotSuctAlphMax[Cr]	Plant potential where transpiration is (1-Alpha)*potential transpiration,Alpha is a small value (e.g. 0.01). Value could be different depend on crop type.	cm	-6000 – -4000 (-5000)	(Crop Library/Water Uptake)
76.	Cq_PotSuctAlphMin[Cr]	Plant potential where transpiration is Alpha*potential transpiration, Alpha is a small value (e.g. 0.01). Value could be different depend on crop type.	cm	-16000 – -14000 (-15000)	(Crop Library/Water Uptake)
77.	Cq_RainWStorCap[Cr]	Rainfall water stored as thin film at leaf surface	mm	0 – 2 (1)	(Crop Library/Rain Interception)
78.	Cq_RelLightMaxGr[Cr]	Relative light intensity at which shading starts to affect tree growth	dimensionless	0 – 1 (1)	(Crop Library/Light Capture)
79.	Cq_RhizEffKaPC[Cr]	Proportional reduction of the apparent adsorption constant for P due to root activity of the crop, expressed as fraction of N_KaPdef per unit crop root length density	m^2 day^{-1}	0 – 0.2 (0)	(Crop Library/Crop effect on nutrient mobility)
80.	Cq_RtAlloc[Cr]	Fraction of crop growth reserves allocated to root biomass in the absence of water or nutrient stress as a function of crop stage (only for Rt_ACType=2).	day^{-1}	(see Cq_RtAlloc table)	(Crop Library)
81.	Cq_RtAllocResp[Cr]	Crop root allocation responsiveness to water or nutrient (the factor currently in minimum supply) stress; 0 = constant root allocation, 1 = linear response to water and nitrogen stress, >1 more-than-proportional response (only for Rt_ACType = 2)	dimensionless	0 – 2 (2)	(Crop Library/Roots)
82.	Cq_RtDiam[Cr]	Crop root diameter. It is used in calculating water and nutrient uptake.	cm	0.05 – 1 (.02)	(Crop Library/Roots)
83.	Cq_SingleCycle?[Cr]	A parameter deciding what happens after fruits are ripe: 1 = annual that dies back, 0 = perennial that returns to crop stage =1.	dimensionless	0 or 1 (1)	(Crop Library/Annual or Perennial?)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
84.	Cq_SLA[Cr]	Crop specific leaf area = green surface area (one-sided) per unit leaf dry weight, for each crop species as a function of crop growth stage. For Cq_Atype =1, .., 5, default values are provided. Cq_AType = 6, .,10 user defined, as before.	$m^2\ g^{-1}$	(see Cq_SLA table)	(Crop Library)
85.	Cq_TimeGen[Cr]	Length of generative stage for each crop. For Cq_Atype =1, .., 5, default values are provided, but can be modified to adopt the default crop parameters to local conditions.	days	0 – 1000 (30)	(Crop Library/Crop Stage)
86.	Cq_TimeVeg[Cr]	Length of vegetative stage for each crop. For Cq_Atype =1, .., 5, default values are provided, but can be modified to adopt the default crop parameters to local conditions.	days	0 – 1000 (60)	(Crop Library/Crop Stage)
87.	Cq_TranspRatio[Cr]	Amount of water needed per unit dry matter production of each crop species. For Cq_Atype =1, .., 5, default values are provided. For Cq_AType=6, .., 10 user defined	$l\ kg^{-1}$	200 – 600 (300)	(Crop Library/Crop Growth)
88.	Cq_WeedType	Weed type. This is user defined. Weed biomass growth follows the rules of crop growth. It takes the same type of parameters as crop. All the related input parameters are in Excel sheet	dimensionless	(5)	Management/Weed Growth
89.	CW_EnergyDrivenEpot?	Switch (1 = yes, 0 = no) to determine whether the crop water demand driven by Epot	dimensionless	(1)	Soil Evaporation
90.	E_BulkDens	Bulk density used in converting soil mass movement to changes in volume of topsoil per zone	$g\ cm^{-3}$	0.5 – 1.6 (1.4)	(Soil Hydraulic)
91.	E_CovEffT[Tree]	Tree cover efficiency factor (per unit tree LAI)	dimensionless	0 – 1 (.5)	(Tree Library/Erosion Protection)
92.	E_EntrailmentCoeffBare-Plot	Entrailment coefficient for sediment movement (Rose equation) in the absence of vegetative soil cover	Ton (soil) $mm^{-1}\ m^2$	0 – 1 (.002)	Soil Erosion and Sedi-mentation
93.	E_ErosiType	Parameter to decide on model of erosion used. 1 = using USLE, 0 = using Rose Equation	dimensionless	0 or 1 (0)	Soil Erosion and Sedi-mentation
94.	E_IntvPloughPlant	Length of ploughing time	julian days	1 – 365 (10)	Management/Tillage
95.	E_PloughBefPlant?	Paramater governing option to plough before planting (0 = no ploughing, 1 = ploughing before planting)	dimensionless	0 or 1 (0)	Management/Tillage
96.	E_PloughDoY	Date of ploughing	julian days	1 – 365 (364)	Management/Tillage
97.	E_PloughY	Year of ploughing	dimensionless	0 – 100 (100)	Management/Tillage
98.	E_RainFac	A multiplier determining impact of rainfall on soil erosion, for calculation soil loss using USLE	dimensionless	0 – 10 (1)	Soil Erosion and Sedi-mentation

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
99.	E_SoilMoveperPlough	Amount of soil moved per ploughing event, for calculation soil loss using USLE	kg m^{-2}	0 – 500 (399)	Soil Erosion and Sedimentation
101.	E_SoilType	Type of soil. 1 = medium, 2 = sandy, 3 = clay	dimensionless	1, 2, 3 (1)	Soil Erosion and Sedimentation
101.	E_TillZone?[Zone]	On/off switch for tilling activity in each zone (0 = no tillage, 1 = with tillage)	dimensionless	0 or 1 (0, 1, 1, 1)	Management/Tillage
102.	Evap_InitSlashM	Initial moisture content of slashed vegetation	fraction	(0.4)	Soil Evaporation
103.	Evap_InitWoodM	Initial moisture content of slashed wood	fraction	(0.25)	Soil Evaporation
104.	Evap_MulchEffSurfLit	Effect of mulch on the amount of water evaporating from the soil	dimensionless	1	Soil Evaporation
105.	Evap_SlashDryFact	Factor determined of water of slashed vegetation will evaporated	fraction	0 – 1 (0.5)	Soil Evaporation
106.	Evap_TransRedFractionBy-Can InterceptedWater	The evaporation of water intercepted by plant canopies will reduce the potential transpiration by satisfying part of the energy-driven potential evapotranspiration; this parameter determines the fraction of canopy interception transpiration that will be reduce from Epot before we determine plant demand. Lower values would reflect: 1) rainfall at night (evaporation not during peak of transpiration) 2) more open landscapes where more dry wind comes in from outside the plot.		(0.5)	Soil Evaporation
107.	Evap_WoodDryFact	Factor determined of water of slashed wood will evaporated	fraction	0 – 1 (0.25)	Soil Evaporation
108.	GHG_LitMinMultiplier	Multiplier of litter mineralization for quick modifications of nitrogen oxide emission	dimensionless	(1)	Soil Water & Nutrient/ Nox emissions
109.	GHG_N_2_per_NOx	Ratio of nitrous and nitric oxide	dimensionless	See graph GHG_N_2perNOx	Soil Water & Nutrient/ Nox emissions
110.	LF_FracGWReleaseAsInflow	The fraction of groundwater that flow out that reaches the simulated zone (this depends on subsoil stratification and landscape characteristics beyond the scope of out current model)	dimensionless	(0)	Agroforestry Zone
111.	LF_GWReleaseFraction	The fraction of the current stock of groundwater that flows out on a daily basis. A stock of groundwater stored uphill depends on the 'number of plots uphill'.	dimensionless	(.05)	Agroforestry Zone

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
112.	LF_SubSurfInflow4	Amount of sub surface water inflow in layer 4	mm day^{-1}	0 – 5 (0)	Agroforestry zone
113.	Mc_Carbon	Proportion of total carbon in plant litter and residue	dimensionless	0 – 0.5 (.42)	Soil Organic Matter and Litter Quality/Litter Quality
114.	Mc_CExtOrg[type]	Carbon concentration of external input	dimensionless	0 – 1 (.4)	Litter Quality/Quality of Ext. Organic Input
115.	Mc_CNRatInitMetab[zone]	Initial C:N ratio metabolic pool of litter	dimensionless	(8)	Soil Organic Matter and Litter Quality/Initial C & N in Litter Pool
116.	Mc_LignExtOrg[Type]	Lignin concentration of external input.	dimensionless	0 – 1 (.2)	Soil Organic Matter and Litter Quality/Quality of Ext. Organic Input
117.	Mc_PolypExtOrg[Type]	Polyphenol concentration of external input	dimensionless	0 – 1 (0)	Soil Organic Matter and Litter Quality/Quality of Ext. Organic Input
118.	Mc_RelKActLit	Decomposition rate of active surface litter pool relative to decomposition rate of active soil fraction pool. It's assumed the decomposition rate of active surface litter and active soil fraction is the same.	dimensionless	(.8)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
119.	Mc_RelKMetabLit	Decomposition rate of metabolic surface litter pool relative to decomposition rate of metabolic soil litter pool. It's adopted from century model, the decomposition rate of metabolic surface litter pool = 0.028 per week = 0.04 per day and the decomposition rate of metabolic soil litter pool = 0.35 per week = 0.05 per day.	dimensionless	(.8)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
120.	Mc_RelKPassLit	Decomposition rate of passive surface litter pool relative to decomposition rate of passive soil fraction pool. It's assumed the decomposition rate of passive surface litter and passive soil fraction is the same.	dimensionless	(1)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
121.	Mc_RelKSlwLit	Decomposition rate of slow surface litter pool relative to decomposition rate of slow soil fraction pool. It's assumed the decomposition rate of slow surface litter and slow soil fraction is the same.	dimensionless	(1)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
122.	Mc_RelKStrucLit	Decomposition rate of structural surface litter pool relative to decomposition rate of structural soil litter pool. It's adopted from century model, the decomposition rate of structural surface litter pool = 0.076 per week = 0.010857 per day and the decomposition rate of structural soil litter pool = 0.094 per week = 0.013429 per day.	dimensionless	(0.808511)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
123.	Mc2_Clay	Proportion of clay in soil (only for soil organic matter type 2)	dimensionless	0 – 1 (.316)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
124.	Mc2_ClayCoeffCref	Coefficient of clay based on tabulated Cref for soil organic matter type 2	dimensionless	(.94)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
125.	Mc2_ CNRatInitMetab[zone]	Initial C:N ratio metabolic pool of soil organic matter	dimensionless	(8)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
126.	Mc2_CorgInitMeth3	Initial soil organic carbon value in soil organic matter pool using Type 3.	gr cm^{-2}	(2)	Soil Organic Matter and Litter Quality/ Initial C & N in SOM Pool
127.	Mc2_CorgpCref	Initial soil organic carbon value in soil organic matter pool using Type 3.	gr cm^{-2}	(.8)	Soil Organic Matter and Litter Quality/ Initial C & N in SOM Pool
128.	Mc2_CrefMeth3	Initial C-ref value in soil organic matter pool using Type 2.	gr cm^{-2}	(3)	Soil Organic Matter and Litter Quality/ Initial C & N in SOM Pool
129.	Mc2_CrefOffset	Constant for C reference tabulated for soil organic matter type 2.	dimensionless	1.256	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
130.	Mc2_KAct	Decay rate for decomposition of active pool of soil organic matter	dimensionless	(.02)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
131.	Mc2_KMetab	Decay rate for decomposition of active pool of soil organic matter	dimensionless	(.05)	Soil Organic Matter and Litter Quality/Other Factors Affecting Decomposition
132.	Mc2_KPass	Decay rate for decomposition of active pool of soil organic matter	dimensionless	(.0000186)	Soil Organic Matter and Litter Quality/Other Factors Affecting Decomposition
133.	Mc2_kRelLayer[SoilLayer]	Factor determined decay rate for decomposition of active, passive and slow pool for each soil layer (relative to decay rate for decomposition for each pool).	fraction	(1, .8, .7, .6)	Soil Organic Matter and Litter Quality/ Other Factors Affecting Decomposition
134.	Mc2_KSlw	Decay rate for decomposition of active pool of soil organic matter	dimensionless	(.000543)	Soil Organic Matter and Litter Quality/Other Factors Affecting Decomposition
135.	Mc2_KStruc	Decay rate for decomposition of active pool of soil organic matter	dimensionless	(.013429)	Soil Organic Matter and Litter Quality/Other Factors affecting Decomposition
136.	Mc2_pH	Soil pH (only for soil organic matter type 2)	dimensionless	(5)	Soil Organic Matter and Litter quality/ Other Factors Affecting Decomposition
137.	Mc2_pHCoeffCref	Coefficient of pH based on tabulated of Cref for soil organic matter type 2	dimensionless	-.156	Soil Organic Matter and Litter Quality/Other Factors Affecting Decomposition
138.	Mc2_RainTransfer[Pool]	Rain factor which control transferring process of litter to SOM pool	dimensionless	.001	Soil Organic Matter and Litter Quality/Litter → SOM Transfer
139.	Mc2_Silt	Proportion of silt in soil (only for soil organic matter type 2)	dimensionless	0 – 1 (.2)	Soil Organic Matter and Litter Quality/Other Factors Affecting Decomposition
140.	Mc2_SiltClayCoeffCref	Coefficient of clay and silt based on tabulated Cref for soil organic matter type 2	dimensionless	(.703219)	Soil Organic Matter and Litter Quality/Other Factors Affecting Decomposition
141.	Mc2_SoilTillTransfer[Pool]	Soil tillage factor which control transferring process of litter to SOM pool	dimensionless	(1)	Soil Organic Matter and Litter Quality/Litter → SOM Transfer

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
142.	Mc2_ SOMDistribution[SoilLayer]	Relative distribution of carbon between different soil layers	fraction	0 – 1 (1, .2, .1, .05)	Soil Organic Matter and Litter Quality/SOM Distribution
143.	Mc2_SOMInitType	Parameter defining methods to initialize soil organic matter pool. Three methods are provided for initializing the soil organic matter pools: Type = 1 the user can specify all pool sizes for all zones, Type = 2 the user can specify the size of all pools relative to those for a forest soil (Cref) that is calculated from soil texture data, Type = 3 the user specifies the Corg and Cref directly, but otherwise follows the procedure of Type 2	dimensionless	1, 2, 3 (1)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
144.	Mc2_WormTransfer[Pool]	Worm factor which control transferring process of litter to SOM pool	dimensionless	0.003 – 0.1 (Struc, Metab and Act = .1; Slow = .3; Pass = .003)	Soil Organic Matter and Litter Quality/ Litter → SOM Transfer
145.	Mn_CNAct	C:N ratio of active pools	dimensionless	5 – 10 (8)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
146.	Mn_CNPass	C:N ratio of passive pools	dimensionless	8 – 15 (11)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
147.	Mn_CNSlw	C:N ratio of slow pools	dimensionless	8 – 15 (11)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
148.	Mn_CNStruc	C:N ratio of structural pools	dimensionless	100 – 200 (150)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
149.	Mn_ExtOrgN[Type,SiNut]	N or P concentration of external input	dimensionless	0 – 0.1 (N = .05, .1; P = .005, .001)	Soil Organic Matter and Litter Quality/Quality of Ext. Organic Input
150.	Mn_FertDissFrac[SiNut]	Daily fraction of fertilizer dissolved	Dimensionless	(N = 0.3, P = 0.5)	Soil Water & Nutrient/Fertilizer Movement

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
151.	Mn_InitAct[Zone]	Initial amount of N in active Litter pool of each zone	mg cm^{-3}	0 – 1 (.00002)	Soil Organic Matter and Litter Quality/Initial C & N in Litter Pool
152.	Mn_InitMetab[Zone]	Initial amount of N in metabolic Litter pool of each zone	mg cm^{-3}	0 – 1 (0)	Soil Organic Matter and Litter Quality/Initial C & N in Litter Pool
153.	Mn_InitPass[Zone]	Initial amount of N in passive Litter pool of each zone	mg cm^{-3}	0 – 1 (.0001)	Soil Organic Matter and Litter Quality/Initial C & N in Litter Pool
154.	Mn_InitSlw[Zone]	Initial amount of N in slow Litter pool of each zone	mg cm^{-3}	0 – 1 (.000001)	Soil Organic Matter and Litter Quality/Initial C & N in Litter Pool
155.	Mn_InitStruc[Zone]	Initial amount of N in structural Litter pool of each zone	mg cm^{-3}	0 – 1 (0)	Soil Organic Matter and Litter Quality/Initial C & N in Litter Pool
156.	Mn_LatFlowFertKm	Runoff flow that causes half of the (undissolved) surface fertilizer to move to the next zone	mm	(10)	Soil Water & Nutrient/Fertilizer Movement
157.	Mn_NutRatAct[P]	Ratio of N to P (N:P) in active organic matter pools	dimensionless	1 – 10 (10)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
158.	Mn_NutRatMetab[P]	Ratio of N to P (N:P) in metabolic organic matter pools	dimensionless	1 – 10 (10)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
159.	Mn_NutRatPass[P]	Ratio of N to P (N:P) in passive organic matter pools	dimensionless	1 – 10 (10)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
160.	Mn_NutRatSlw[P]	Ratio of N to P (N:P) in slow organic matter pools	dimensionless	1 – 10 (10)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool
161.	Mn_NutRatStruc[P]	Ratio of N to P (N:P) in structural organic matter pools	dimensionless	1 – 10 (10)	Soil Organic Matter and Litter Quality/C:N Ratio of Litter Pool

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
162.	Mn2_InitAct[Zone]	Initial amount of N in active SOM pool of each zone	mg cm^{-3}	0 – 1 (.2)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
163.	Mn2_InitMetab[Zone]	Initial amount of N in metabolic SOM pool of each zone	mg cm^{-3}	0 – 1 (0)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
164.	Mn2_InitPass[Zone]	Initial amount of N in passive SOM pool of each zone	mg cm^{-3}	0 – 1 (3.9)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
165.	Mn2_InitSlw[Zone]	Initial amount of N in slow SOM pool of each zone	mg cm^{-3}	0 – 1 (1)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
166.	Mn2_InitStruc[Zone]	Initial amount of N in structural SOM pool of each zone	mg cm^{-3}	0 – 1 (0)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
167.	Mn2_ PassRelLayer[SoilLayer]	Proportional distribution of passive pool	fraction	(1, 1.2, 1.4, 1.6)	Soil Organic Matter and Litter Quality/Initial C & N in SOM Pool
168.	N_BypassMacroi[Zone]	Prefential flows of nutrients in the leachate relative to average concentration * water flow; values < 1 indicates retardation of nutrients due to bypass flow of water in macropores at soil layer i	dimensionless	0 – 2 (1)	Soil Water and Nutri-ent/Macropore Bypass Flow
169.	N_DiffCoef[SiNut]	Nitrogen diffusion coefficient	cm^2 day^{-1}	0 - 1 (N = 1, P = .76896)	Soil Water and Nutrient /Diffusivity coefficient
170.	N_FracNO3i[Zone]	Fraction of NO_3 of total N in *i*-th soil layer	dimensionless	0 - 1 (0.4)	Soil Water and Nutri-ent/Nitrate Fraction
171.	N_ImInit[Zone,SiNut]	Initial amount of nutrient in immobile pool of each zone	mg cm ^{3}	0 – 0.1 (N = .05, P = .01)	Soil Water and Nutri-ent /Initial Immobile Nutrient
172.	N_KaNH4i[Zone]	Apparent (instantaneous) adsorption constant or ratio of amount NH_4 adsorbed and amount in solution for *i*-th layer	mg cm^{-3}	0 – 1 (5)	Soil Water and Nutrient/Adsorption constant for N

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
173.	N_KaNO3i[Zone]	Apparent (instantaneous) adsorption constant or ratio of amount NO_3 adsorbed and amount in solution for i-th layer	mg cm^{-3}	0 – 1 (.3)	Soil Water and Nutrient /Adsorption constant for N
174.	N_KaPDefi[Zone]	Apparent (instantaneous) adsorption constant for inorganic P, or ratio of amount of inorganic P adsorbed ant the amount in soil solution; the adsorption constant depends on the P concentration on soil solution and is read in a tabular form (as graphical input parameter).	mg cm^{-3}	(see N_KaPDef*i* table)	(Phosphorus/to P sorption data)
175.	N_Lat4InflowRelConc	Nutrient concentrations in the incoming sub-surface flows into zone 4, relative to the current average nutrient concentration in that layer across all zones in the simulated area	dimensionless	0 – 10 (1)	Agroforestry Zone
176.	N_NIniti[Zone,SiNut]	Initial amount of nutrient in soil layer i of each zone	mg cm^{3}	0 – 0.5 (N layer 1 = .003, layer 2 – 4 = .01 ; P layer 1 = .1, layer 2 = .08, layer 3 – 4 = .04)	For P, (Phosphorus/Initial P availability Index per Zone and Layer) For N, (Nitrogen)
177.	N_NutMobi[SiNut]	Relative rate of transfer from the 'immobile' pool of nutrients to the 'mobile' or sorbed pool, due to processes other than root activity in soil layer i	day^{-1}	0 – 0.02 (0)	Soil Nutrient/Nutrient Mobilization
178.	N_RtSynloci	Root synlocation, or degree to which roots of the crop and tree are co-occurring within the various soil layers, affecting the way in which benefits of rhizosphere modification are shared; 1 = sharing of rhizosphere modifications by all roots present, based on their share in total root length, 0 = complete monopoly by roots modifying the rhizosphere	dimensionless	0 – 1 (.5)	Roots and Mycorrhiza
179.	N_UseNGassLossEst?	A switch determining simulate system with gaseous N losses. 0 = no gaseous N losses, 1 = with gaseous N losses	dimensionless	(0)	Soil Water & Nutrient
180.	N15_Addi [Zone]	Initial amount of N^{15} in soil layer i of each zone	mg cm^{-3}	(0)	N^{15} model sector
181.	P_BurnLab	Amount of labour involved in burning the field per unit simulated filed	person days ha^{-1}	(see excel sheet Profitability)	(Profitability)
182.	P_CfertPrice[SiNut,Price]	Cost of fertilizer at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Profitability)	(Profitability)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
183.	P_CHarvLab[Cr]	Amount of labour involved in harvesting crop products per unit dry weight	person days Mg^{-1} per cropping season	(see excel sheet Crop Library)	(Crop Library/Profit-ability)
184.	P_CNuFerAppperCrop-Season	Number of fertilizer application per cropping season	dimensionless	Any integer value (2)	Profitability
185.	P_CPestContLab[Cr]	Amount of labour involved in pest control per cropping season	person days ha^{-1} per cropping season	(see excel sheet Crop Library)	(Crop Library/Profit-ability)
186.	P_CPestContPrice[Price]	Amount of direct costs (outside labour) involved in pest control per cropping season	currency unit per ha^{-1} per cropping season	(see excel sheet Profitability)	(Profitability)
187.	P_CPlantLab[Cr]	Amount of labour involved in planting per cropping season	person days ha^{-1} per cropping season	(see excel sheet Crop Library)	(Crop Library/Profit-ability)
188.	P_CropProfThreshold	Threshold value for crop profitability. Relevan to parameter P_UseCropStopRule? = 1	Currency unit	(100000)	Management/Ending a Crop Cycle
189.	P_CSeedPrice[Cr,Price]	Cost of crop seed per kg at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Crop Library)	(Crop Library/Profit-ability)
190.	P_CWeedLab[Cr]	Amount of labour involved in weeding per cropping season	person days ha^{-1} per cropping season	(see excel sheet Crop Library)	(Crop Library/Profit-ability)
191.	P_CyieldPrice[Cr, Price]	Price of crop yield per unit dry weight at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Crop Library)	(Crop Library/Profit-ability)
192.	P_DiscountRate	Discount rate (% per year) that applies to both social and private prices	% $year^{-1}$	(see excel sheet Profitability)	(Profitability)
193.	P_ExtOrgPrice [Type,Price]	Price of external organic input	currency unit kg^{-1}	(see excel sheet Profitability)	(Profitability)
194.	P_FenceMatCost[Price]	Price of off-farm material used for building or maintaining a fence around the field	currency unit ha^{-1}	(see excel sheet Profitability)	(Profitability)
195.	P_LabourforPestContrl ?	A switch 0 0r 1 for pesticide application related to the use of labour (1 = pesticide application, 0 = no pesticide application)	dimensionless	0 or 1	Profitability
196.	P_LabourforWeed ?	A switch 0 0r 1 for weeding application related to the use of labour (1 = weeding application, 0 = no weeding application)	dimensionless	0 or 1	Profitability

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
197.	P_TFruitHarvLab	Amount of labour involved in harvesting fruits per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
198.	P_TFruitPrice[Price]	Price of tree fruit yield per unit dry weight at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
199.	P_TLatexHarvLab	Amount of labour involved in harvesting latex per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
200.	P_TLatexPrice[Price]	Price of tree latex yield per unit dry weight at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
201.	P_TNuFerApp[Tree]	Number of fertilizer application per year	dimensionless	Any integr value (2)	Profitability
202.	P_TPlantLab	Amount of labour involved in planting trees per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
203.	P_TPrunLab[Tree]	Amount of labour involved in pruning trees per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
204.	P_TPrunPrice[Price]	Price of tree prunings harvested from the field per unit dry weight at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
205.	P_TSeedPrice[Price]	Costs of tree planting material per unit initial tree biomass at social and private prices, respectively.	currency unit $tree^{-1}$	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
206.	P_TWoodHarvLab	Amount of labour involved in harvesting wood products per unit dry weight	person days kg=1	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
207.	P_TWoodPrice[Price]	Price of tree wood product yield per unit dry weight at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Tree Library)	(Tree Library/Profit-ability)
208.	P_UnitLabCost[Price]	Cost per unit labour at social and private prices, respectively	currency unit person $days^{-1}$	(see excel sheet Profitability)	(Profitability)
209.	P_UseCropStopRule?	A switch determining the simulation will continue to growth crop or not when the previous crop profitability lower than the threshold value. 0 means continue to growth crop, 1 = stop to growth crop	dimensionless	(0)	Management/Ending a Crop Cycle
210.	PD_CeatenBy[Cr,Animals]	Fraction of crop component lost if eaten by animals. Default animals are pigs, monkey, locust, nematode, goat, buffalo and birds	dimensionless	0 – 1 (0)	(Crop Library/Sensitivity to Pest Damage)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
211.	PD_CFrugivore?[Animals]	A switch determining the presence of attack by each default animal. 0 = animals is not a crop frugivore,1 = animal is frugivore	dimensionless	0 or 1 (0)	Pest and Disease
212.	PD_CFrugivory[Cr]	Constant daily fraction of crop fruit biomass removed due to the action of frugivores	dimensionless	0 – 1 (0)	Pest and Diseases
213.	PD_CHerbivore?[Animals]	A switch determining the presence of attack by each default animal. 0 = animals is not a crop herbivore,1 = animal is herbivore	dimensionless	0 or 1 (0)	Pest and Disease
214.	PD_CHerbivory[Cr]	Constant daily fraction of crop leaf biomass removed due to the action of herbivores	dimensionless	0 – 1 (0)	Pest and Diseases
215.	PD_CRhizovore?[Animals]	A switch determining the presence of attack by each default animal. 0 = animals is not a crop rhizovore,1 = animal is rhizovore	dimensionless	0 or 1 (0)	Pest and Disease
216.	PD_CRhizovory[Cr]	Constant daily fraction of crop root biomass removed due to the action of rhizovores	dimensionless	0 – 1 (0)	Pest and Diseases
217.	PD_FenceBuildDOY	Schedule for day of fencing for each fencing event. A graphical input.	julian days	(see PD_Fence-BuildDOY graph)	Pest and Disease
218.	PD_FenceBuildLab	Amount of labour needed to build fence for each fencing event. A graphical input.	person days	(see PD_Fence-BuildLab graph)	Pest and Disease
219.	PD_FenceBuildY	Schedule for year of fencing for each fencing event A graphical input.	dimensionless	(see PD_Fence-BuildY graph)	Pest and Disease
220.	PD_FenceDecK	Daily fractional decay of fence quality	day^{-1}	0 – 1 (.02)	Pest and Diseases
221.	PD_FenceFullQua	Maximum quality of fence	dimensionless	1 – 4 (2)	Pest and Diseases
222.	PD_FenceMaint?	Switch determining fence maintenance. 1 = fence maintenance will be done automatically, 0 = no fence maintenance	dimensionless	0 or 1 (0)	Pest and Disease
223.	PD_FenceMUnit	Unit improvement of fence quality once it falls below the threshold set in PD_FenceQThresh	dimensionless	0 – 2 (.25)	Pest and Disease
224.	PD_FenceQThresh	Threshold of (relative) fence quality below which labour will be used to repair the fence	dimensionless	0 – 2 (1.1)	Pests and Disease
225.	PD_HalfFenceTime	Time constant of decay of fence quality: time interval after which quality is reduced by 50%	days	0 – 365 (50)	Pest and Disease

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
226.	PD_ JumptheFence?[animals]	The degree to which animals are deterred by a fence from entering the plot	-	0 – 1 (0)	Pest and Diseases
227.	PD_ PopDensOutside[animals]	Population density outside the plot, influencing the presence	-	0 or 1	Pest and Diseases
228.	PD_TEatenBy?[Animals]	A switch determining tree attacks by specific animals. Default animals are pigs, monkey, locust, nematode, goat, buffalo and birds. 0 = no attack, 1 = attacked	0 or 1 (0)	0 – 1 (0)	(Tree parameters/Pest Impacts)
229.	PD_TFrugivore?[Animals]	A switch determining the presence of attack by each default animal. 0 = animals is not a tree frugivore,1 = animal is frugivore	dimensionless	0 or 1 (0)	Pest and Disease
230.	PD_Tfrugivory&Abort[Tree]	Constant daily fraction of tree fruit biomass removed due to the action of frugivores	-	0 – 1 (0)	Pest and Diseases
231.	PD_THerbivore?[Animals]	A switch determining the presence of attack by each default animal. 0 = animals is not a tree herbivore,1 = animal is herbivore	dimensionless	0 or 1 (0)	Pest and Disease
232.	PD_THerbivory[Tree]	Constant daily fraction of tree leaf biomass removed due to the action of herbivores	-	0 – 1 (0)	Pest and Diseases
233.	PD_TLignivory[Tree]	Constant daily fraction of tree woody stem biomass removed due to the action of lignivores	-	0 – 1 (0)	Pest and Diseases
234.	PD_TLignovore?[Animals]	A switch determining the presence of attack by each default animal. 0 = animals is not a tree lignovore,1 = animal is lignovore	dimensionless	0 or 1 (0)	Pest and Disease
235.	PD_TRhizovore?[Animals]	A switch determining the presence of attack by each default animal. 0 = animals is not a tree rhizovore,1 = animal is rhizovore	dimensionless	0 or 1 (0)	Pest and Disease
236.	PD_TRhizovory[Tree]	Constant daily fraction of tree root biomass removed due to the action of rhizovores	-	0 – 1 (0)	Pest and Diseases
237.	Rain_AType	A number 1, 2 or 3 to decide rainfall rate (1= rainfall rate follows precipitation data from external file, rainfall rate follows tabulated data, 2 = rainfall rate follows random generator, 3= rainfall rate follows tabulated monthly total data)	dimensionless	1, 2 or 3 (1)	Rainfall
238.	Rain_BoundHeaLi	Boundary value between heavy and light rain (only for Rain_ AType=1)	mm	20 – 30 (25)	Rainfall
239.	Rain_CoeffVar2	Coefficient variation of rainfall in mm, used in rainfall generated randomly (Rain_Atype=2)	dimensionless	0 – 1 (.05)	Rainfall
240.	Rain_CoeffVar3	Coefficient variation of rainfall in mm, rainfall based on tabulated monthly rainfall (Rain_Atype=3)	dimensionless	0 – 1 (.05)	Rainfall

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
241.	Rain_Cycle?	Parameter governing ways to read rainfall data. Corresponds to Rain_AType=1 (0 = use multiple year rainfall data, 1 = use 1 year data in cycle/continuously)	dimensionless	0 or 1 (1)	Rainfall
242.	Rain_Data	Actual daily rainfall data. Entered as graphical function or read from Wanulcas.xls (Stella non-CRT users only). Corresponds to Rain_AType=1.	mm	(see table in excel sheet weather)	(WEATHER)
243.	Rain_DayP	Probability of raining each day as a function of Julian day scaled monthly. Corresponds to Rain_AType=2 and 3.	dimensionless	0 – 1 (.32)	Rainfall
244.	Rain_GenSeed	Seed Random Generator. For Rain_AType=2 and 3.	dimensionless	1 – 32767 (300)	Rainfall
245.	Rain_Heavy	Average precipitation rate of on a heavy rain day; for Rain_AType=2.	mm day^{-1}	0 – 100 (42)	Rainfall
246.	Rain_HeavyP	Probability of heavy rain; for Rain_AType=2.	dimensionless	0 – 1 (.5)	Rainfall
247.	Rain_IntensCoefVar	Coeficient variance of rain intensity. Rain intensity is a factor affecting water infiltration. It is assumes to follow normal distribution with an average of Rain_IntensMean and standard deviation Rain_IntensMean*Rain_IntensCoefVar.	dimensionless	(.3)	Rainfall
248.	Rain_IntensMean	Average rain intensity per hour. Rain intensity is a factor affecting water infiltration. It is assumes to follow normal distribution with an average of Rain_IntensMean and standard deviation Rain_IntensMean*Rain_IntensCoefVar	mm hr^{-1}	(50)	Rainfall
249.	Rain_IntercDripRt	The rate of water dripping from water on interception surface	mm hr^{-1}	(10)	Rainfall
250.	Rain_IntMult	Indicates the maximum temporary storage of water on interception surfaces	dimensionless	(3)	Rainfall
251.	Rain_Light	Average precipitation rate of a light rain day day; for Rain_AType=2.	mm day^{-1}	0 – 40 (9)	Rainfall
252.	Rain_MaxIntDripDur	Maximum value of water interception delay before start to dripping	mm hr^{-1}	(.5)	Rainfall
253.	Rain_MonthTot	Tabulated data of monthly rainfall; for Rain_AType=3. Entered as graphical function or read from Wanulcas.xls (Stella non-CRT users only).	mm $month^{-1}$	(see Rain_MonthTot graph)	Rainfall
254.	Rain_Multiplier	Multiplier of rainfall for quick modifications of rainfall amount	dimensionless	0 – 4 (1)	RUN & OUTPUT SECTION

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
255.	Rain_PondFlwRt	The rate at which water ponding on the surface will actually flow to a neighbouring zone or plot	mm hr^{-1} per m of zone width	(10)	Rainfall
256.	Rain_PondStoreCp	The storage capacity of water ponding on the surface	mm	(5)	Rainfall
257.	Rain_Weight[Zone]	Input weight value to decide amount of rain falling on each zone relative to other zones (eg. equal rainfall in each zone on area basis means 1:1:1:1)	dimensionless	0 – 10 (1)	Rainfall
258.	Rain_YearStart	Initial year based on rainfall data at which simulation starts	dimensionless	any integer value (0)	Rainfall
259.	Rain_UniorBimodal?	An option to have one or two season of rainfall	dimensionless	2	Rainfall
260.	Rain_Probabiity	Ratio between season 1 and season 2	dimensionless	0.5	Rainfall
261.	Rain_OffSetValue	Influence value of dry month. High value indicates low amount of rainfall at dry season.	dimensionless	-0.5	Rainfall
262.	Rain_ShapeMax	Maximum value of shape. Shape is a basic pattern of rainfall simulator model that use SINUS as the distribution function. This value will be used to determine Pattern value.	dimensionless	1.5	Rainfall
263.	Rain_ShapeMin	Minimum value of shape.	dimensionless	-0.5	Rainfall
264.	Rain_Pattern1Max	Maximum value of pattern. Pattern is calculated from shape value which is the maximum and the minimum value have been adjusted to the maximum and minimum value of total monthly rainfall.	dimensionless	0.06	Rainfall
265.	Rain_Pattern1Min	Minimum value of pattern.	dimensionless	-0.01	Rainfall
266.	Rain_WettestMonthSea-son1	The wettest month of the first season (January – June)	dimensionless	1	Rainfall
267.	Rain_WettestMonthSea-son2	The wettest month of the second season (July – December)	dimensionless	7	Rainfall
268.	Rain_PeakinessSeason1	The sharpness of the first peak. High value indicates sharper peak.	dimensionless	1	Rainfall
269.	Rain_PeakinessSeason2	The sharpness of the second peak. High value indicates sharper peak.	dimensionless	12	Rainfall
270.	Rain_WeibullParam	Parameter of Weibull distribution. This Weibull parameter is used to predict the value of daily cumulative frequency of rainfall data.	dimensionless	0.93	Rainfall

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
271.	Rain_MonthlyMeanRain-fallMax	Maximum value of monthly mean rainfall	mm	333	Rainfall
272.	Rain_MonthlyMeanRain-fallMin	Minimum value of monthly mean rainfall	mm	102	Rainfall
273.	Rain_ NumberWetDaypM[Month]	The number of wet day for each month	day	See graph	Rainfall
274.	Rain_MonthlyMeanTotal-rainfall [Month]	Monthly mean rainfall on the wet day	mm	See graph	Rainfall
275.	Rain_RelWetPersistencepM [Month]	Monthly relative wet persistence	dimensionless	See graph	Rainfall
276.	Rt_ACType	Parameter governing type of root density data for crop. 0=Lrv data available, 1=Lrv calculated using exponential function model where length root area is constant, 2= Lrv calculated using exponential function model where length root area is derived from root biomass	dimensionless	0, 1, or 2 (0)	Roots and Mycorrhiza/ Crop Root
277.	Rt_ATType	Parameter governing type of root density data for tree. 0=Lrv data available, 1=Lrv is constant calculated using ellipticall function model, 2= Lrv is calculated using elliptical function but dynamically changes according to water or N stress	dimensionless	0, 1 or 2 (0)	Roots and Mycorrhiza/ Tree Root
278.	Rt_CDecDepth[Cr]	Parameter governing decrease of crop root with depth; corresponds to Rt_ACType=1 and Cq_AType.	m^{-1}	0 - 10 (7)	(Crop Library/Roots)
279.	Rt_CDistResp[Cr]	Responsiveness of crop root distribution to the depth at which uptake of the currently limiting resource (water, N or P) is most successful. Value 0 = no response to stress, 0 – 1 = mild response, 1 = proportional change to inverse of relative depth of uptake, > 1 = strong response. Only for Rt_ACType = 2.	dimensionless	0 – 3 (1)	(Crop Library/Roots)
280.	Rt_CHalfLife[Cr]	Crop root half-life (only for Rt_ACType=2)	days	30 – 100 (50)	(Crop Library/Roots)
281.	Rt_CLraConst[Cr]	Total root length per unit area. It is used to calculate crop root density in exponential decrease model (Rt_ACType=1). Also corresponds to Cq_AType.	$cm\ cm^{-2}$	0 – 150 (100)	(Crop Library/Roots)
282.	Rt_CLrvmi[Cr]	Maximum crop root length density in i-th soil layer; corresponds to Rt_ACType=0 and Cq_A Type.	$cm\ cm^{-3}$	0 – 15 (layer 1 = 5, layer 2 = 3, layer 3 = .3, layer 4 = 0)	(Crop Library/Roots)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
283.	Rt_CMultiplier	Multiplier of root for quick modifications of crop root length density	dimensioless	(1)	Root and Mycorrhiza
284.	Rt_CSRL[Cr]	Specific root length (length per unit dry weight) of crop roots	$m\ g^{-1}$	50 – 100(200)	(Crop Library/Roots)
285.	Rt_MCHypDiam	Diameter of crop mycorrhizal hyphae	cm	0.001 – 0.05 (.01)	Roots & Mycorrhiza/ Mycorrhiza
286.	Rt_MCHypL	Length of crop mycorrhizal hyphae per unit infected root length	dimensionless	10 – 100 (100)	Roots & Mycorrhiza/ Mycorrhiza
287.	Rt_MCInfFraci	Fraction of crop roots that is mycorrhizal (infected) in i-th soil layer	dimensionless	0 – 1 (layer 1 =.05, layer 2 =.25, layer 3 = .05, layer 4 = 0)	Roots & Mycorrhiza/ Mycorrhiza
288.	Rt_MTHypDiam	Diameter of tree mycorrhizal hyphae	cm	0.001 – 0.05 (.01)	Roots & Mycorrhiza/ Mycorrhiza
289.	Rt_MTHypL	Length of tree mycorrhizal hyphae per unit infected root length	dimensionless	10 – 100 (100)	Roots & Mycorrhiza/ Mycorrhiza
290.	Rt_MTInfFraci[Zone]	Fraction of tree roots that is mycorrhizaal (infected)	dimensionless	0 – 1 (0)	Roots & Mycorrhiza/ Mycorrhiza
291.	Rt_TAlloc[Tree]	Fraction of tree growth reserves allocated to roots in the absence of water or nutrient stress (only for Rt_ATType=2)	dimensionless	0 – 1 (.1)	(Tree Library/Roots)
292.	Rt_TAllocResp[Tree]	Responsiveness of tree root allocation to stress factors; 0 = constant root allocation, 1 = linear response to water and nitrogen stress, >1 more-than-proportional response (only for Rt_ACType = 2),	dimensionless	0 – 2 (2)	(Tree Library/Roots)
293.	Rt_TDecDepthC[Tree]	Parameter governing decrease of tree root with depth ; for Rt_ATType=1	m^{-1}	0 – 10 (3)	(Tree Library/Roots)
294.	Rt_TDistResp[Tree]	Responsiveness of crop root distribution to the depth at which uptake of the currently limiting resource (water, N or P) is most successful. Value 0 = no response to stress, 0 – 1 = mild response, 1 = proportional change to inverse of relative depth of uptake, > 1 = strong response. Only for Rt_ACType = 2.	dimensionless	0 – 5 (2)	(Tree Library/Roots)
295.	Rt_TDistShapeC[Tree]	Tree root distribution shape for Rt_ATType=1 and 2; for a value of 1 root length density decreases as much with horizontal as with vertical distance to the tree stem	dimensionless	0 – 2 (.05)	(Tree Library/Roots)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
296.	Rt_THalfLife[Tree]	Tree root half life (only for Rt_ATType=2)	days	30 – 150 (60)	(Tree Library/Roots)
297.	Rt_THostEffForT1[Tree]	An option for simulation root parasitism tree 1 on others tree root	dimensionless	(0)	Root Parasitism
298.	Rt_TLengDiam1[Tree]	Length of (branch) roots of a tree root with a proximal (at stem base) diameter of 1 cm; Intercept (a) of allometric equation (RootLength = a StemDiameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	cm cm-b	0.01 – 1 (10)	(Tree Library/Roots)
299.	Rt_TLengDiamSlope[Tree]	Power coefficient (b) of allometric equation (RootLength = a StemDiameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	dimensionless	1 – 3 (1.5)	(Tree Library/Roots)
300.	Rt_TLraX0[Tree]	Total root length per unit area at X(distance to tree)=0 (tree stem). for Rt_ATType=1	cm cm^{-2}	0 – 150 (1)	(Tree Library/Roots)
301.	Rt_TLrvDatai[Zone,Tree]	Tree root density in soil layer .i in each zone; for Rt_ATType=0	cm cm^{-2}	0 – 15 (see excel sheet Tree Library/Roots)	(Tree Library/Roots)
302.	Rt_TMultiplier	Multiplier of root for quick modifications of tree root length density	dimensionless	(1)	Root and Mycorrhiza
303.	Rt_TProxGini	Distribution coefficient of proximal root diameters (CumFreq = (Diam/Diammax)TProxGini of a tree, used in calculation of the specific root length of a tree root system	dimensionless	0.001 – 10 (.3)	(Tree Library/Roots)
304.	Rt_TWghtDiam1[Tree]	Biomass of a (branched) tree root with a proximal (at stem base) diameter of 1 cm; Intercept (a) of allometric equation (Root weight = a StemDiameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	kg $cm^{-b\,z}$	0.01 – 1 (.5)	(Tree Library/Roots)
305.	Rt_TWghtDiamSlope[Tree]	Power coefficient (b) of allometric equation (RootWeight = a StemDiameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	dimensionless	1 – 3 (2.3)	(Tree Library/Roots)
306.	S&B_2ndFireafterPileup	Number of days between puile up and secondary burn event	days	1 – 100 (5)	Management/Slash and Burn
307.	S&B_CritMoist	Limit value for internal + adhering (intercepted from rainfall) moisture content of slashed necromass; below this value necromass is categorized as dry and fire can take place	l kg^{-1}	0 – 1(.05)	Management/Slash and Burn

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
308.	S&B_DailyDeadWood-LitTransf	Rate of transfer of daily dead wood litter per day	fraction day^{-1}	(0.005)	Slash and Burn
309.	S&B_DailyNecromLitTransf	Rate of transfer of necromass litter per day	fraction day^{-1}	(0.01)	Slash and Burn
310.	S&B_DeadWoodFuelFact	Temperature of the fire per unit dry weight of fuel in dead wood	$^{o}C\ kg^{-1}$	0 – 100 (.1)	Management/Slash and Burn
311.	S&B_FirImpPSorption	Fire impacts on P sorption, as a function of soil surface temperature increase	dimensionless	(see table in excel sheet Slash&Burn)	Management/Slash and Burn
312.	S&B_FirIndPMobiliz	Fire impact on mobilization fraction of P from the inorganic P immobile pool, as a function of soil surface temperature increase	dimensionless	(see table in excel sheet Slash&Burn)	Management/Slash and Burn
313.	S&B_FirMortSeedBank	Fractional mortality in the weed seed bank as a function of soil surface temperature increment	dimensionless	(see table in excel sheet Slash&Burn)	Management/Slash and Burn
314.	S&B_FuelLoadFactor	Temperature of the fire per unit dry weight of fuel in slashed necromass and structural surface litter	$^{o}C\ kg^{-1}$	0 – 100 (10)	Management/Slash and Burn
315.	S&B_MaxDryingPer	The latest time after slashing when fire can occur; if the fuel does not get dry enough before this time, no fire will be occur	days	1 – 200 (30)	Management/Slash and Burn
316.	S&B_MinDryingPer	The earliest time after slashing that fire can occur	days	0 – 100 (20)	Management/Slash and Burn
317.	S&B_NecroBurnFrac	Fraction of surface necromass burnt as a function of fire temperature at the soil surface.	dimensionless	(see table in excel sheet Slash&Burn)	Management/Slash and Burn
318.	S&B_NutVolatFracN	Volatilization fraction of N in the burnt necromass, as a function of soil surface temperature increment	dimensionless	(see table in excel sheet Slash&Burn)	(Slash&Burn)
319.	S&B_NutVolatFracP	Volatilization fraction of P in the burnt necromass, as function of soil surface temperature increment	dimensionless	(see table in excel sheet Slash&Burn)	(Slash & Burn)
320.	S&B_pHRecFrac	Daily recovery fraction of soil pH in the topsoil from its post-fire towards its pre-fire value	fraction	0.001–0.1 (.01)	Management/Slash and Burn
321.	S&B_PileUpFrac	Fraction of dead wood pile up after slash and burn event	fraction	0 – 1 (0.7)	Management/Slash and Burn

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
322.	S&B_PSorpRecFrac	Daily recovery fraction of the P_sorption in the topsoil from its post-fire towards its pre-fire value	fraction	0.001–0.1 (.01)	Management/Slash and Burn
323.	S&B_ScorchWRemFrac	Fraction of scorched wood removed after slash and burn event	fraction	0 – 1 (.3)	Management/Slash and Burn
324.	S&B_SlashDOY	A graphical input tabulating day of year at which slashing is performed	julian days	(see S&B_Slash-DOY graph)	Management/Slash and Burn
325.	S&B_SlashYear	A graphical input tabulating year at which slashing is performed	dimensionless	any integer value (100)	Management/Slash and Burn
326.	S&B_SOMBurnFrac	Fraction of all SOM pools in the topsoil (Layer 1) respired (C) or mineralized (N & P) as a function of soil surface temperature increment	dimensionless	(see table in excel sheet Slash&Burn)	Management/Slash and Burn
327.	S&B_SurfLitBurnFrac	Fraction of all surface litter respired (C) or mineralized (N & P) as a function of soil surface temperature increment	dimensionless	(see table in excel sheet Slash&Burn)	Management/Slash and Burn
328.	S&B_TimetoPileUp	Number of days between primary burn and pile up (redistribution across the zones) for a secondary burn	days	1 – 100 (15)	Management/Slash and Burn
329.	S&B_TimetoWoodRem	Number of days between primary burn and removal of scorched wood	days	1 – 50 (10)	Management/Slash and Burn
330.	S&B_TTempTol[Tree]	Maximum fire temperature that a tree can tolerate. Temperature above the value will induce tree mortality	^{0}C	40 – 90 (75)	(Tree Library/ Slash&Burn)
331.	S&B_WatRetRecFrac	Daily recovery fraction of soil water retention in the topsoil from its post-fire towards its pre-fire value	fraction	0.001 – 0.1 (0.005)	Management/Slash and Burn
332.	S&B_WetnessTempImp	Fractional reduction in fire temperature per unit of moisture content of the fuel	fraction	0 – 1 (.5)	Management/Slash and Burn
333.	S_BDBDRefDecay	Relative rate of decay of the bulk density, returning the surface infiltration rate toward S_SurfInfiltrPerKsatDef and the saturated hydraulic conductivity towards S_KSatDefV	day^{-1}	0 – 0.1 (.001)	Soil Structure
334.	S_C_RtStrucFormFrac	Fraction of contribution of crop root decay on root channels	fraction per m	(.1)	Soil Structure
335.	S_KSatDefVi	Saturated hydraulic conductivity of the soil in the absence of macropore structure, as derived from texture-based pedotransfer functions. Read and calculation from Wanulcas.xls. Input needed to run pedotranfer refer to the sheet pedotranfer	cm day^{-1}	1 – 500 (layer 1 = 319, layer 2 = 54, layer 3 = 45, layer 4 = 40)	(Soil Hydraulic)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
336.	S_KsatHperVi	Ratio of saturated hydraulic conductivity in horizontal and vertical direction for layer i	dimensionless	0 – 5 (1)	Soil Structure/K Sat ratio
337.	S_KSatInitVi[Zone]	Saturated hydraulic conductivity of the soil at the macropore structure existing at the start of the simulation. Read and calculation from Wanulcas.xls. Input needed to run pedotranfer refer to the sheet pedotranfer	cm day^{-1}	1 – 500 (layer 1 = 319, layer 2 = 54, layer 3 = 45, layer 4 = 40)	(Soil Hydraulic)
338.	S_KSatVDeepSub	Saturated hydraulic conductivity of the soil below layer 4, determining the rate of vertical drainage from the soil column	cm day^{-1}	1 – 100 (20)	Soil Structure
339.	S_RelSurfInfiltrInit[Zone]	Surface infiltration rate at the start of the simulation relative to its default value	dimensionless	100 – 10000 (1000)	Soil Structure
340.	S_RelWormLiti	Relative impact of 'worms' (soil fauna) on increase of saturated hydraulic conductivity in each layer	dimensionless	0 – 1 (1, 0.6, 0.3, 0.1)	Soil Structure
341.	S_RelWormSurf	Relative impact of 'worms' (soil fauna) increase of infiltration rate of the soil surface	dimensionless	0 – 1 (1)	Soil Structure
342.	S_SoilStructDyn?	Switch determining dynamics of soil structure (0 = false, 1 = true) based on decay and re-creation of macropores by soil fauna above the texture-based default values	day^{-1}	0 or 1 (0)	Soil Structure
343.	S_SurfInfiltrPerKsatDef [Zone]	Ratio of surface infiltration and Ksat for the first soil layer in the default condition of the soil as defined by the pedotransfer function	dimensionless	25 – 10000 (25)	Soil Structure
344.	S_T_RtStrucFormFrac	Fraction of contribution of tree root decay on root channels	fraction per m	(.3)	Soil Structure
345.	S_WormsLikeLitMetab	Activity (in arbitrary units) of soil fauna (“worms'') per unit of organic inputs in the litter metabolic pool	m^2 kg^{-1}	0.00001 – 0.1 (.00001)	Soil Structure
346.	S_WormsLikeLitStruc	Activity (in arbitrary units) of soil fauna (“worms'') per unit of organic inputs in the litter structural pool	m^2 kg^{-1}	0.0000005 – 0.1 (.0000005)	Soil Structure
347.	S_WormsLikeSOMMetab	Activity (in arbitrary units) of soil fauna (“worms'') per unit of organic inputs in the SOM metabolic pool	m^2 kg^{-1}	0.000001 – 0.1 (.000001)	Soil Structure
348.	S_WormsLikeSOMStruc	Activity (in arbitrary units) of soil fauna (“worms'') per unit of organic inputs in the SOM structural pool	m^2 kg^{-1}	0.00000005 – 0.1 (.00000005)	Soil Structure
349.	T_ApplyFBA?[Tree]	Switch (1 = yes, 0 = no) to determine whether the allocation of biomass from the canopy to the wood (branches + stem) pools is governed by the fractal branching parameters (allometric equations).	dimensionless	0 or 1 (1)	Tree Parameters

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
350.	T_ApplyPalm?[Tree]	Switch (1 = yes, 0 = no) to determine whether the allocation of biomass to storage pool follows oil palm rule.	dimensionless	0 or 1 (0)	(Tree Library/Fruit)
351.	T_BarkThickness	Bark thickness to calculate target of latex content, the thickness is following the growth of the tree.	cm	0 – 1 (see graph)	Management/Latex Production
352.	T_BrownBast?	Switch (1 = yes, 0 = no) to determine whether the rubber tree infected by brownbast.	dimensionless	0 or 1 (0)	Management/Latex Production
353.	T_CanBiomInit[Tree]	Initial amount of biomass in tree canopy (leaf and small stems)	kg per tree	0 – 1 (0)	Tree parameters
354.	T_CanHMax[Tree]	Maximum height of tree canopy	m	0 – 15 (8.2)	(Tree Library/Canopy)
355.	T_CanMaintResp	Fraction of canopy biomass use for maintenance respiration	dimensionless	(0.001)	Management/Latex Production
356.	T_CanShape[Tree]	Factor determining in which part of the tree leaves are concentrated. A value of 1 gives an even spread of tree leaves over the alley, a higher value (eg 2) concentrates tree leaves above the hedgerow	dimensionless	0 – 2 (.567)	(Tree Library/Canopy)
357.	T_CanWidthMax[Tree]	Maximum tree canopy width, half the canopy width (radius).	m	0 – 10 (4.655)	(Tree Library/Canopy)
358.	T_ConcFruit[SiNut,Tree]	Nutrient concentration in fruit component	dimensionless	0 – 0.1 (N = .02, P = .002)	(Tree Library/N-P concentration)
359.	T_ConcGroRes[SiNut,Tree]	Nutrient concentration in carbohydrate reserves	dimensionless	0 – 0.1 (N = .01, P = .0005)	(Tree Library/N-P concentration)
360.	T_ConcLf[SiNut,Tree]	N concentration in leaf component of tree	dimensionless	0 – 0.1 (N = .0173, P = .0009)	(Tree Library/N-P concentration)
361.	T_ConcRt[SiNut,Tree]	Nutrient concentration in tree roots (only for Rt_ATType=2)	dimensionless	0 – 0.1 (N = .0122, P = .0006)	(Tree Library/N-P concentration)
362.	T_ConcTwig[SiNut,Tree]	Nutrient concentration in twig component of tree	dimensionless	0 – 0.1 (N = .00073, P = .0016	(Tree Library/N-P concentration)
363.	T_ConcWood[SiNut,Tree]	Nutrient concentration in wood component of tree	dimensionless	0 – 0.1 (N = .0047, P = .0008)	(Tree Library/N-P concentration)
364.	T_DiamBiom1[Tree]	Biomass of a tree of diameter 1 cm; Intercept (a) of allometric equation (Branch biomass = a StemDiameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	kg	0.01 – 1 (.6513)	(Tree Library/Allometric branching)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
365.	T_DiamBranch1[Tree]	Intercept (a) of allometric equation (Tree branch biomass = a Diameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	kg	0.01 – 1 (.0334)	(Tree Library/Allometric branching)
366.	T_DiamCumLit1[Tree]	Cumulative litterfall expected for a stem diameter of 1 cm. Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	kg	0.01 – 1 (.0302)	(Tree Library/Allometric branching)
367.	T_DiamLfTwig1[Tree]	Intercept (a) of allometric equation (Leaf &Twigbiomass = a Stem-Diameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	kg cmb	0.01 – 1 (.9656)	(Tree Library/Allometric branching)
368.	T_DiamSlopeBiom[Tree]	Power coefficient (b) of allometric equation (Branch biomass = a StemDiameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	dimensionless	0 – 3 (2.0937)	(Tree Library/Allometric branching)
369.	T_DiamSlopeBranch[Tree]	Power coefficient (b) of allometric equation (Tree branch biomass = a Diameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	dimensionless	0 – 3 (2.4195)	(Tree Library/Allometric branching)
370.	T_DiamSlopeCumLit[Tree]	Power coefficient (b) of the alloemtric equation describing the increase of cumulative litterfall with stem diameter. Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	dimensionless	0 – 3 (3.0937)	(Tree Library/Allometric branching)
371.	T_DiamSlopeLfTwig[Tree]	Power coefficient (b) of allometric equation (Leaf&Twig biomass = a StemDiameterb). Calculation from Functional Branch Analysis (FBA). Input needed to run FBA refer to tree parameterization	dimensionless	1 – 3 (1.7270)	(Tree Library/Allometric branching)
372.	T_DiamTreshHarv[Tree]	Tree diameter of timber harvested	cm	100	Management/Timber Harvesting
373.	T_DOY 1 LfFlush[Tree]	Day of the first cycle of leaf flush	julian days	1 – 365 (1)	Tree parameters/Tree leaf phenology)
374.	T_DOY 2 LfFlush[Tree]	Day of the second cycle of leaf flush	julian days	1 – 365 (400)	Tree parameters/Tree leaf phenology
375.	T_DOY SeaLitFall1Start[Tree]	Day when the first season of leaf starts dropdown	julian days	1 – 365 (400)	Tree parameters/Tree leaf phenology
376.	T_DOY SeaLitFall2Start[Tree]	Day when the second season of leaf starts dropdown	julian days	1 – 365 (400)	Tree parameters/Tree leaf phenology

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
377.	T_DOY_Compl1LfFall[Tree]	Day when the first season of leaf completely dropdown	julian days	1 – 365 (400)	Tree parameters/ Tree leaf phenology
378.	T_DOY_Compl2LfFall[Tree]	Day when the second season of leaf completely dropdown	julian days	1 – 365 (400)	Tree parameters/ Tree leaf phenology
379.	T_DOYFlwBeg[Tree]	The earliest day in a year when tree start to flowers	julian days	1 - 365 (200)	(Tree Library/ Growth stage)
380.	T_DOYFlwEnd[Tree]	The latest day in a year when tree start to flowers	julian days	1 - 365 (250)	(Tree Library/ Growth stage)
381.	T_DynTapping Frac	Dynamic value of fraction of latex stock would be tapped everyday. The simulation will run using this dynamic value when T_BrownBast? switch to 1	dimensionless	See graph	Management/Latex Production
382.	T_ExpRetThresh	Threshold value of expected return to labour		(30)	Management/Latex Production
383.	T_FracSeaLitFall1[Tree]	Fraction of tree canopy become litterfall	dimensionless	0 – 1 (1)	(Tree parameter/ Tree leaf phenology)
384.	T_FruitAllocMax[Tree]	Allocation of biomass to fruit each day	kg m^{-2} day^{-1}	0 – 1 (0)	(Tree Library/Fruit)
385.	T_FruitAllocStage[Tree]	Graphical input parameter as a function of tree stage that determine how much fruit will produce from maximum fruit allocation	dimensionless	0 – 1 (see T_FruitAllocStage graph)	Management/Fruit Harvesting
386.	T_FruitHarvFrac[Tree]	Harvest index for fruit. Constant value for every fruiting season	dimensionless	0 – 1 (0)	Management/Fruit Harvesting
387.	T_FruitMoistFrac[Tree]	Standard moisture content for expressing marketable fruit of each tree	dimensionless	0 – 1 (0)	Profitability
388.	T_GenLitFracMax[Tree]	Fraction of fruit will drop	dimensionless	0 – 1 (.05)	Management/Fruit Harvesting
389.	T_GenLitStage[Tree]	Graphical input parameter as a function of tree stage that determine how many fruit will drop	dimensionless	0 – 1 (see T_GenLitStage graph)	Management/Fruit Harvesting
390.	T_GraphPhenol?[Tree]	Parameter governing an option to simulate tree phenology using graph. Value 0 means tree phenology using phenology parameters, value 1 means tree phenology using graph	dimensionless	0 or 1 (0)	Tree parameter/Tree leaf phenology
391.	T_GroMax[Tree]	Maximum growth rate of hedgerows at full canopy closure	kg m^{-2} day^{-1}	0 – 0.1 (.014)	(Tree Library/ Growth)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
392.	T_GroResFrac[Tree]	Fraction of tree carbohydrate reserves converted to biomass during regrowth stage after pruning	day^{-1}	0 – 0.5 (.025)	(Tree Library/ Growth)
393.	T_GroResInit[Tree]	Initial amount of tree carbohydrates as reserves of tree potential growth	kg per tree	0 – 1 (0.25)	Tree parameters
394.	T_GrowthResp			(1)	Management/Latex Production
395.	T_HeartWoodAllocAft-Pruned?	Parameter governing an option to simulate heartwood. Value 0 means after pruning no sapwood biomass that allocated to heart-wood biomass, value 1 means after pruning all sapwood biomass allocated to heartwood biomass.	dimensionless	(0)	Tree parameter/Tree stem (sapwood & heartwood)
396.	T_InitStage[Tree]	Initial stage of tree when it was planted. If tree already growing at the start of simulation, it is the stage at the start of simulation time	dimensionless	0 – 2 (0)	(Tree Library/Growth stage)
397.	T_KillDOY[Tree]	Schedule date, day of year to kill tree	julian days	1 – 365 (1)	Management/Killing Trees
398.	T_KillY[Tree]	Schedule date, year to kill tree	dimensionless	any integer value (1000)	Management/Killing Trees
399.	T_KLight[Tree]	Tree canopy (leaves Wonent) extinction light coefficient = the ef-ficiency of tree foliage in absorbing light	dimensionless	0 – 1 (.7)	(Tree Parameters/ Light Capture)
400.	T_LAIMax[Tree]	Maximum value of LAI in the tree canopy	dimensionless	0 – 5 (4)	(Tree Library/ Canopy)
401.	T_LAIMinMaxRatio[Tree]	Parameter describing canopy thickness/dense. Value 1 is maximum thickness	dimensionless	0 – 1 (1)	(Tree Library/ Canopy)
402.	T_LatexFormResp	Respiration for Latex formation		(0.01)	Management/Latex Production
403.	T_LatexMainResp	Fraction of latex production use for maintenance respiration	dimensionless	(0.0001)	Management/Latex Production
404.	T_LatexMoistFrac[Tree]	Standard moisture content for expressing marketable latex of each tree	dimensionless	0 – 1 (.14)	Profitability
405.	T_LatexRecoveryTime	Time for latex to recover.		(7)	Management/Latex Production
406.	T_LifallDroughtFrac[Tree]	Fraction of tree biomass becomes litterfall due to drought	day^{-1}	0 – 1 (.01)	(Tree Library/Lit-terfall)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
407.	T_LifallThreshWStress[Tree]	Threshold value for tree litterfall due to drought	dimensionless	0 – 1 (.7)	(Tree Library/Litterfall)
408.	T_LifallWeight[Zone,Tree]	Input weight value governing amount of tree litterfall going into each zone relative to other zones (eg. 1:1:1:1 means equal mulch given in each zones on area basis)	dimensionless	0 – 10 (1,1, 1, 1)	Litterfall
409.	T_LignLifall[Tree]	Lignin concentration of tree litterfall (eg. 20%=0.2)	dimensionless	0 – 1 (.43)	(Tree Library/Litter Quality)
410.	T_LignPrun[Tree]	Lignin concentration of pruned tree biomass (eg. 20%=0.2)	dimensionless	0 – 1 (.4)	(Tree Library/Litter Quality)
411.	T_LignRt[Tree]	Lignin concentration of tree root	dimensionless	0 – 1 (.4)	(Tree Library/Litter Quality)
412.	T_LWR[Tree]	Leaf Weight Ratio = leaf dry weight per unit shoot dry weight	dimensionless	0 – 5 (.494)	(Tree Library/Growth)
413.	T_MaxBarkLatexContent	Maximum of latex content in bark	dimensionless	0 – 1 (0.3)	Management/Latex Production
414.	T_MaxGrowthUtFrac			(.2)	Management/Latex Production
415.	T_MaxUseFrac			(.1)	Management/Latex Production
416.	T_MemExpY	How much a farmer forget previous yield (latex yield) and use it as a basis for his expectation of future latex yield, value in 0 - 1. 0 = he remembers fully, 1 = he forgets fully	dimensionless	0 - 1 (0.1)	Management/Latex Production
417.	T_ MinDiamforTappingcm[Tree]	Minimum tree diameter for tapping	cm	10 – 15 (15)	Management/Latex Production
418.	T_MycMaxInf[Tree]	Fraction of tree roots infected by mychorrhiza for a soil layer where the Rt_MTInfFrac parameter is 1	dimensionless	0 – 1 (.3)	(Tree Library/Mycorrhiza
419.	T_NFixDayFrac[Tree]	Fraction of current N deficit derived from atmospheric N_2 fixation per day for each tree if T_NFixVariable = 1 (('true')	day^{-1}	0 - 1 (.125)	(Tree Library/N Fixation)
420.	T_NFixDWMaxFrac[Tree]	Maximum fraction of the T_GroRes[Dw] pool that can be respired for N_2 fixation if T_NFixVariable = 0 (('false')	day^{-1}	0 - 0.5 (.05)	(Tree Library/N Fixation)
421.	T_NFixDWUnitCost[Tree]	Dry weight cost for respiration per unit N_2 fixation, if T_NFixVariable = 0 (('false')	kg [dw] g^{-1} [N]	0 – 1 (0)	(Tree Library/N Fixation)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
422.	T_NfixResp[Tree]	Responsiveness of N_2 fixation to N stress (N in biomass divided by N target), if T_NFixVariable = 0 (('false')	dimensionless	0 – 5 (0)	(Tree Library/N Fixation)
423.	T_NFixVariable?[Tree]	Switch (0 = false, 1 = true) to choose between variable (N-stress dependent) versus constant N_2 fixation as fraction of N deficit	dimensionless	0 or 1 (0)	(Tree Library/N Fixation)
424.	T_NlifallRed[SiNut,Tree]	Reducing factor for nutrient concentration of tree litterfall which depend on type of tree	dimensionless	0 – 2 (.7 for N and P)	(Tree Library/Litterfall)
425.	T_NutMobT[SiNut]	Relative rate of transfer, per unit root length density (cm cm^{-3}), from the 'immobile' pool of nutrients to the 'mobile' or sorbed pool, due to Crop root activity	m^2 day^{-1}	0 – 0.02 (0)	(Tree Library/Root Impacts on Nutrient Mobility)
426.	T_PanelQuality1[Tree]	Bark available for tapping at the first period of tapping			Management/Latex Production
427.	T_PanelQuality2[Tree]	Bark available for tapping at the second period for tapping			Management/Latex Production
428.	T_PanelRecoveryTime	Recovery time of bark have been tapped that would be available for next period of tapping	days	(7300)	Management/Latex Production
429.	T_PlantDOY[Tree]	Schedule for date of planting time. Entered from Wanulcas.xls	julian days	1 – 365 (see table in excel sheet Tree Management)	(Tree Management)
430.	T_PlantY[Tree]	Schedule for year of planting time. Entered from Wanulcas.xls	dimensionless	any integer value (see table in excel sheet Tree Management)	(Tree Management)
431.	T_PolypLifall[Tree]	Polyphenol concentration of tree litterfall (eg. 3 %=0.03)	dimensionless	0 – 1 (0)	(Tree Library/Litter Quality)
432.	T_PolypPrun[Tree]	Polyphenol concentration of pruned tree biomass (eg. 3 %=0.03)	dimensionless	0 – 1 (0)	(Tree Library/Litter Quality)
433.	T_PolypRt[Tree]	Polyphenol concentration of tree root	dimensionless	0 – 1 (0)	(Tree Library/Litter Quality)
434.	T_PrunDoY[Tree]	Schedule for date of pruning. Entered from Wanulcas.xls	julian days	1 – 365 (365)	(Tree Management)
435.	T_PrunFracC[Tree]	Fraction of canopy that gets pruned, for T_PrunType = 0. Constant for every pruning	dimensionless	0 – 1 (0)	Managements/PruningEvents
436.	T_PrunFracC[Tree]	Fraction of tree canopy gets pruned, for T_PrunFrac? = 0	dimensionless	0 – 1 (1)	Management/PruningEvents

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
437.	T_PrunFracD[Tree]	Fraction of tree canopy that gets pruned, for T_PrunFrac? = 1	dimensionless	0 – 1 (1)	(Tree Management)
438.	T_PrunHarvFracC[Tree]	Fraction of pruned canopy that harvested (not return to the system), for T_PrunType? = 0. Constant for every pruning.	dimensionless	0 – 1 (0)	Managements/PruningEvents
439.	T_PrunHarvFracD[Tree]	Fraction of tree pruned biomass harvested. Value changes overtime	dimensionless	0 or 1 (0)	(Tree Management)
440.	T_PrunLimit	Critical total LAI of all trees shadowing the crop zone, triggering a pruning event	dimensionless	0 – 5 (100)	Management/PruningEvent
441.	T_PrunMoistFrac[Tree]	Standard moisture content for pruned biomass of each tree	dimensionless	0 – 1 (.14)	Profitability
442.	T_PrunPlant?[Tree]	Parameter governing pruning decision. 1 = tree is automatically pruned before crop planting, 0 = tree does not automatically pruned	dimensionless	0 or 1 (1)	Management/PruningEvent
443.	T_PrunRecov[Tree]	Time needed for tree to recover after pruning	days	0 – 30 (14)	Management/PruningEvent
444.	T_PrunStageLimit[Tree]	The latest crop stage at which automatic pruning is still performed. Corresponds to T_PrunPlant? = 1	dimensionless	1 – 2 (1.8)	Management/PruningEvent
445.	T_PrunType?	This parameter govern the type of pruning events. 0 = Pruning determined automatically based on canopy denseness (tree LAI). Associated with T_PrunLimit and Tree_StageLimit. 1 = Pruning determined by calender. Assciated with Pruning section in sheet Tree Management, Wanulcas.xls	dimensionless	0 (0 or 1)	Managements/PruningEvents
446.	T_PrunWeight[Zone,Tree]	Input weight value governing amount of tree pruning going into each zone relative to other zones (eg. equal pruned biomass given in each zones on area basis means 1:1:1:1)	dimensionless	0 – 10 (0, 1, 1, 1)	Management/PruningEvent
447.	T_PrunY[Tree]	Schedule for year of pruning. Entered from Wanulcas.xls	dimensionless	any integer value (100)	(Tree Management)
448.	T_RainWStorCap[Tree]	Rainfall intercepted by tree stored as thin film at leaf surface	dimensionless	(1)	(Tree Library/Rain Interception)
449.	T_RecoveryExp			(.01)	Management/Latex Production
450.	T_RelLatexFormPriority			(.7)	Management/Latex Production
451.	T_RelLightMaxGr[Tree]	Relative light intensity at which shading starts to affect tree growth	dimensionless	0 - 1 (.5)	(Tree Library/Light Capture)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
452.	T_RelPosinZone[Tree]	Position of each tree within each zone; 0 means the position of the trees on the left side of its zone, 1 means on the right side of its zone.	dimensionless	0 – 1 (0)	(AF System)
453.	T_RestDayperTappingDay	Number of days between tapping event	days	(see T_RestDayper TappingDay)	Management/Latex Production
454.	T_RhizEffKaPT	Proportional reduction of the apparent adsorption constant for P due to root activity of the crop, expressed as fraction of N_KaP-def per unit tree root length density	m^2 day^{-1}	0 – .2 (0)	(Tree Library/Root impacts on P mobil-ity)
455.	T_RtDiam[Tree]	Tree root diameter. It is used in calculating water and nutrient uptake. For all root type.	cm	.05 – 3 (.1)	(Tree Library/Roots)
456.	T_Rubber?	Switch (1 = yes, 0 = no) to determine whether the tree growth as rubber tree, there is allocation of biomass to latex pool	dimensionless	0 or 1 (0)	(Tree Library/ Growth)
457.	T_SapWoodScaling Rule	Power coefficient of conversion of diameter of sapwood to heartwood. Default value 1 means no increasing of diameter heartwood	dimensionless	0 – 1 (1)	Tree parameter/Tree stem (sapwood & heartwood)
458.	T_SLA[Tree]	Tree specific leaf area = tree leaf surface area per unit leaf dry weight	m^2 kg^{-1}	0 – 30 (7.87)	(Tree Library/ Growth)
459.	T_SlashLabour	Amount of labour involved in slashing the field per unit simu-lated filed as a function of biomass slashed	person days	(see T_SlashLab graph)	Management/Slash and Burn
460.	T_SlashSellWoodFrac[Tree]	Indicates the fraction of wood that is removed from the plot at the time of slashing the vegetation	dimensionless	0 – 1 (0)	Management/Slash and Burn
461.	T_StageAftPrun[Tree]	Tree growth stage after pruning	dimensionless	0 – 2 (1)	(Tree Library/Growth stage)
462.	T_Tapatall?	Switch (1 = yes, 0 = no) to determine whether the tree will tapped or not	dimensionless	0 or 1 (0)	Management/Latex Production
463.	T_TapGirthFraction	Fraction of girth for tapped	dimensionless	0.3 – 0.5 (0.5)	Management/Latex Production
464.	T_TappableHeight[Tree]	Maximum length of stem bark can be tapped	cm	100 – 150 (100)	Management/Latex Production
465.	T_TappDOW	Tapping day of work	days	380	Management/Latex Production
466.	T_TappingFrac	Constant value of fraction of latex stock would be tapped eve-ryday	dimensionless	0 – 1 (0.5)	Management/Latex Production

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
467.	T_TappingFracMultiplier	Quick modification on dynamic value of fraction of latex stock would be tapped	dimensionless	(1)	Management/Latex Production
468.	T_TappingSlice	Bark thickness of tapping	cm	0.3 – 0.5 (0.35)	Management/Latex Production
469.	T_Temp2	Temperature for maintenance respiration	dimensionless	(see T_Temp2 graph)	Management/Latex Production
470.	T_TempRespMaint	A graphical relation between temperature and maintenance respiration	dimensionless	(see T_TempResp-Maint graph)	Management/Latex Production
471.	T_TimeGenCycle[Tree]	Length of generative cycles of tree	days	any integer value (150)	(Tree Library/Growth stage)
472.	T_TimeVeg[Tree]	Length of vegetative cycles of tree	days	any integer value (720)	(Tree Library/Growth stage)
473.	T_TranspRatio[Tree]	Amount of water needed per unit dry matter production of tree	$l\ kg^{-1}$	0 – 500 (300)	(Tree Library/Growth)
474.	T_TranspRatioTime	Graphical input parameter as a function of tree stage that determine the dynamic of tree transpiration per unit biomass production	-	-	Tree Parameter
475.	T_TreesperHa[Tree]	Tree plant density	dimensionless	any integer value (400)	(AF System)
476.	T_WoodBiomInit[Tree]	Initial amount of biomass in tree stem	kg per tree	0 – 1 (0)	Tree Parameters
477.	T_WoodDens[Tree]	Wood density of each tree species	$kg\ m^{-3}$	(750)	(Tree Library)
478.	T_WoodFracHRemain	Wood height remain after pruning. If you do not want to harvest wood/timber when pruning makes sure this is a high value, eg. 100.	m	0-100 (100)	Management/Pruning Events/Other Pruning Parameters
479.	T_WoodHarvDOY[Tree]	Schedule for date of pruning. Entered from Wanulcas.xls	julian days	1 – 365 (364)	(Tree Management)
480.	T_WoodHarvFrac[Tree]	Fraction Harvested wood	dimensionless	0 – 1 (.95)	Management/Timber Harvesting
481.	T_WoodHarvY[Tree]	Schedule for year of timber harvesting. Entered from Wanulcas.xls	dimensionless	Any integer value (100)	(Tree Management)
482.	T_WoodHInit[Tree]	Initial value of tree bare stem height (tree height excluded canopy)	m	0 – 15 (0)	Tree Parameters

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
483.	T_WoodMaintResp	Fraction of wood biomass use for maintenance respiration	dimensionless	(0.000001)	Management/Latex Production
484.	T_WoodMoistFrac[Tree]	Standard moisture content for expressing marketable wood of each tree	dimensionless	0 – 1 (0)	Profitability
485.	Temp_AType	A number governing type of soil temperature data used in the simulation(0= constant value of soil temperature , 1 =read from monthly average data,2=read from daily data which is read from external file)	dimensionless	1, 2 or 3 (1)	Soil Temperature
486.	Temp_Cons	Soil temperature throughout the simulation; corresponds to Temp_AType=0	0^C	15 – 40 (28)	Soil Temperature
487.	Temp_DailyData	Actual daily data of soil temperature; corresponds to Temp_AType=2. Read from Wanulcas.xls	0^C	(see table in excel sheet weather)	(WEATHER)
488.	Temp_DailyPotEvap	Daily potential evaporation. Entered from Wanulcas.xls	mm day^{-1}	(see table in excel sheet weather)	(WEATHER)
489.	Temp_EvapPotConst	Amount of water evaporating from top soil in absence of plant cover	mm day^{-1}	0 – 10 (3)	Soil Evaporation
490.	Temp_MonthAvg	Monthly average of soil temperature; corresponds toTemp_AType=1. Entered as graphical function	0^C	(see Temp_MonthAvg graph)	Soil Temperature
491.	Temp_PotEvapConst?	Parameter governing type of soil evaporation potential data. 1 = constant throughout simulation, 0 = daily data, 2 = monthly data based on thornthwaite calculation	dimensionless	0 or 1 (1)	Soil Evaporation
492.	TW_DrivenEnergyEpot?	Switch (1 = yes, 0 = no) to determine whether the tree water demand driven by Epot	dimensionless	(0)	Soil Evaporation
493.	TW_PotSuctAlphMax[Tree]	Plant potential where transpiration is (1-Alpha)*potential transpiration, where Alpha is a small value (e.g. 0.01)	cm	-7000 – -3 000 (-5000)	(Tree Library/Water Uptake)
494.	TW_PotSuctAlphMin[Tree]	Plant potential where transpiration is Alpha*potential transpiration, where Alpha is a small value (e.g. 0.01)	cm	-30000 – -10000 (-15000)	(Tree Library/Water Uptake)
495.	W_FieldCapkCriti[Zone]	Field capacity determined by a threshold rate of subsequent drainage (Kcrit) that is set in the pedotransfer worksheet; the actual field capacity used is the maximum of this value and the field capacity derived from the height above a groundwater table. Read and calculation from Wanulcas.xls (pedotransfer). Input needed to run pedotransfer refer to the sheet pedotransfer	m^3 water m^{-3} soil	(see table in excel sheet Soil Hydraulic)	(Soil Hydraulic)

No.	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link location in Excel)
496.	W_Hyd?	Parameter governing water hydraulic lift application in model. 1= apply hydraulic lift in overall water balance, 0=otherwise	dimensionless	0 – 1 (0)	Run & Output Section
497.	W_HydEqFraction	Fraction of water hydraulic lift	fraction	(.1)	Soil Water and Nutri-ent
498.	W_PhiPxi[Zone]	Graphs showing relationship between pressure head in i-th soil layer of each zone and matrix flux potential (the index x refers to the plants with the highest (H), lowest (L), medium-high (MH) or medium low (ML) rank of root water potential), but the graphs will be identical. Read and calculation from Wanulcas.xls (pedotransfer). Input needed to run pedotranfer refer to the sheet pedotranfer	$cm^2\ day^{-1}$	(see table in excel sheet Soil Hydraulic)	(Soil Hydraulic)
499.	W_PhiThetai[Zone]	Matrix flux potential at a given theta/soil water content in layer I of each zone. Read and calculation from Wanulcas.xls (pedotransfer). Input needed to run pedotranfer refer to the sheet pedotranfer	$cm^2\ day^{-1}$	(see table in excel sheet Soil Hydraulic)	(Soil Hydraulic)
500.	W_PThetai[Zone]	Graphs showing relationship between volumetric soil water content and pressure head in i-th soil layer of each zone. Read and calculation from Wanulcas.xls (pedotransfer). Input needed to run pedotranfer refer to the sheet pedotranfer	cm	(see table in excel sheet Soil Hydraulic)	(Soil Hydraulic)
501.	W_ThetaInacci[Zone]	Amount of volumetric soil water in i-th soil layer of each zone not available for plant. It is value of volumetric soil water at pF= 4.2 or P = -16000. Read and calculation from Wanulcas.xls (pedotransfer). Input needed to run pedotransfer refer to the sheet pedotrasnfer	$l\ m^{-2}\ day^{-1}$	(see table in excel sheet Soil Hydraulic)	(Soil Hydraulic)
502.	W_ThetaIniti[Zone]	Initial volumetric soil water content related to water saturated pore volume in i –th soil layer of each zone. Current values are 1, 0.9, 0.8, 0.7 for layer 1…4, respectively	fraction	0 – 1	Soil Water and N/ Initial Soil Water
503.	W_ThetaPi[Zone]	Graphs showing relationship between pressure head in i-th soil layer of each zone and volumetric soil water content. Read and calculation from Wanulcas.xls (pedotransfer). Input needed to run pedotransfer refer to the sheet pedotransfer	cm	0 – 0.5 (see table in excel sheet Soil Hydraulic)	(Soil Hydraulic)
504.	W_ThetaPMax[Zone]	Volumetric soil water content at a given maximum soil potential at top layer. Read and calculation from Wanulcas.xls (pedotransfer). Input needed to run pedotransfer refer to the sheet pedotransfer	cm	(see table in excel sheet Soil Hydraulic)	(Soil Hydraulic)

Appendix 8. Statistical criteria for model evaluation result according to Loague and Green (1991)

Criterion	Symbol	Calculation formula	Range	Optimum
Maximum error	ME	$Max\left\| P_i - O_i \right\|_{i=1}^{n}$	≥ 0	0
Root mean square	RMSE	$\left(\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n} \right)^{\frac{1}{2}} * \frac{100}{O_{mean}}$	≥ 0	0
Coefficient of determination	CD	$\frac{\sum_{i=1}^{n}(Oi - O_{mean})^2}{\sum_{i=1}^{n}(P_i - O_{mean})^2}$	≥ 0	1
Modelling efficiency	EF	$\frac{\left(\sum_{i=1}^{n}(Oi - O_{mean})^2 - \sum_{i=1}^{n}(P_i - O_i)^2 \right)}{\sum_{i=1}^{n}(Oi - O_{mean})^2}$	≤ 1	1
Coefficient of residual mass	CRM	$\frac{\left(\sum_{i=1}^{n} Oi - \sum_{i=1}^{n} P_i \right)}{\sum_{i=1}^{n} O_i}$	≤ 1	0

P_i = predicted values, O_i = observed values, n = number of samples and O_{mean} is the mean of the observed data.

Appendix 9. Other Useful parameters and their definition (parameters which can be input or output which are not yet at users interface layer)

No	Acronym	Definition	Dimensions	Default value	Model Sector
1.	C_GroResMobFrac	Fraction of crop growth reserves that is remobiilze into yield and root component	dimensionless	0.95	Crop Growth
2.	C_NDemand	Amount of Nitrogen or Phosphorus demanded by crop per day; for a crop biomass less than 2 Mg/ha demand is based on 5% N, above that (after canopy closure) on 1% N	kg ha^{-1}	output	Crop Growth
3.	C_NUptTot	Total amount of Nitrogen or Phosphorus in all soil layers potentially available for crop uptake per day	g m^{-2}	output	Crop Growth
4.	CW_DemandAct	Actual amount of crop water demand per day. Potential demand reduced by plant water potential.	l m^{-2}	output	Crop Water
5.	CW_UptTot	Total amount of water uptake by crop from all soil layers per day in each zone	l m^{-2}	output	Crop Water
6.	C_SeedConc[PlantComp]	Nutrient concentration on seed. Value for DW =1, N = 0.05 and P = 0.005	-	see definition	Crop Growth
7.	Evap_Surf	Amount of water evaporates from top soil per day in each zone	l m^{-2}	output	Soil Evaporation
8.	GHG_GWP_CH4	Global Warming Potential for CH4. Global Warming potential is the warming effect of a trace gas on the atmosphere. It differs between trace gases due to different atmospheric lifetime and different heat absorption capacity. It is expressed per molecule basis relative to CO2	-	15	GHG & Denitrification
9.	GHG_GWP_NO2	Global Warming Potential for NO2	-	310	GHG & Denitrification
10.	Mc_LitterC	Amount of carbon in dead plant biomass	g m^{-2}	output	Litter C
11.	Mn_LitterNInpN [Zone,SiNut]	Amount of Nitrogen or Phosphorus in litter layer	g m^{-2}	output	Litter N
12.	N_ExchLittLay1 [Zone,SiNut]	Mineralisation Nitrogen or Phosphorus in litter layer	g m^{-2}	output	N Layer 1
13.	N_SomMini Exch [Zone,SiNut]	Mineralisation of Nitrogen or Phosphorus in soil layer i	g m^{-2}	output	N Layer 2-4
14.	Rt_CLrvt	Crop root growth as a function of time	cm cm^{-3} day^{-1}	output	Crop Root
15.	S_BDEqPower	Power coefficient (b) of the allometric equation describing the decreasing of bulk density later effect on surface infiltration and saturated hydraulic conductivity	dimensionless	0.5	Soil Structure Dynamic
16.	T_BiomAllTrees	Total amount of aboveground biomass for all trees	kg m^{-2}	output	Tree Growth

No	Acronym	Definition	Dimensions	Default value	Model Sector
17.	T_HarvPrunCum[Tree]	Total pruned tree biomass harvested	kg m^{-2}	output	Tree Growth
18.	T_LifallCum[Tree]	Cumulative amount of tree litterfall	kg m^{-2}	output	Tree Growth
19.	T_PrunCum	Cumulative amount of tree pruned biomass	kg m^{-2}	output	Tree Growth
20.	T_WatStressMem	A parameter influencing the effect of drought on litterfall.	-	0.75	Tree Water Parameter
21.	TF_AbRelSizePow[Tree]	Input parameter in oil palm module	-	2	Tree Fruit
22.	TF_AvgDWpFruit[Tree]	Average dry weight of oilpalm fruit	kg m^{-2}	-	Tree Fruit
23.	TF_FemSinkperBunch	Graphical input parameter in oil palm module as a function of fruit stage	-	-	Tree Fruit
24.	TF_FirstBudtoFlowerInit [Tree]	Number of phyllochron time units before sex determination during flower development	-	25	Tree Fruit
25.	TF_InitFruitpBranch [Tree]	Input parameter in OilPalm module	-	500	Tree Fruit
26.	TF_MaleSinkperBunch	Graphical input parameter in oil palm module as a function of fruit stage	-	-	Tree Fruit
27.	TF_MaleThresh[Tree]	Input parameter in OilPalm module	-	0.17	Tree Fruit
28.	TF_MTrresptoWStress[Tree]	Input parameter in OilPalm module	-	0	Tree Fruit
29.	TF_Phyllocrontime[Tree]	Input parameter in oil palm module	-	15	Tree Fruit
30.	TF_PhysAgeInit[Tree]	Phyllochron age at time of planting or start of simulation. Input parameter in oil palm module	-	15	Tree Fruit
31.	TF_StageAbortSens	Graphical input parameter in oil palm module as a function of fruit stage	-	-	Tree Fruit
32.	TF_WatStressAbortFrac[Tree]	Input parameter in OilPalm module	-	0.1	Tree Fruit
33.	TW_Alpha	A small value determing plantt maximum and minimum transpiration. Plant potential for maximum transpiration'(TW_PotSuctAlphMax, unit in cm) is defined as (1- TW_Alpha)*potential transpiration and plant potential for minimum transpiration'(TW_PotSuctAlphMin, unit in cm) is defined as TW_Alpha*potential transpiration.	-	0.1	Tree Water
34.	TW_AxResFactor	For a 10 m distance and a demand of 5 mm day-1 we expect the need for an additional gradient of 2.5 bar = 2500 cm; the factor is thus 5/250 = 0.02	-	0.02	Tree Water
35.	TW_L	Coefficient related to tree root conductivity	cm day^{-1}	10^{-5}	Tree Water
36.	TW_PotSuctBuff	Hydrostatic gradient to overcome transport resistance in wet soil l	cm	0.05	Tree water parameter
37.	W_PMax	Maximum value of soil potential in positive value	cm	0	Water layer 1
38.	W_SeepScalar	A constant that determine how much water will infiltrate to the deeper soil layer when soil water content go beyond field capacity.	fraction	0	Water layer 1…4

Appendix 10. Rainfall simulator within WaNuLCAS 4.0

WaNuLCAS, like many other hydrological and ecological models, needs daily rainfall data as input. Such a dataset is however not always readily available or reliable because, for example due to high cost of buying the daily data from a professional weather record institution, equipment failure or human error in reading the daily rainfall amount from installed equipment in the field or rainfall records that tend to accumulate rainfall over several days so wet and dry days tend to be clumped together. Some research also needs an extrapolation of rainfall events, e.g. for simulations of hydrological process over one or more 30 years climate scenario windows into the future for specified global circulation models and climate change scenarios.. An appropriate method to generate daily rainfall data is thus necessary. The common ('Markov chain') way to generate daily rainfall basically consists of two steps: i) simulating rainfall occurrence, i.e. determining whether or not a day is a rainy day or not, and ii) for rainy days, determine the amount of rainfall.

Determining whether or not a day is a rainy day

Rainfall occurrence is usually simulated by one of two types of Markov chain model. One is a two-state (wet, dry) Markov chain where the order (first, second or third) indicates the number of preceding days that influences the probability that the next day is a rainy day or not. Another is a multi-state first-order Markov chain. The commonest is the two-state first-order Markov chain describing probability for four rainfall occurrences: probability that today and previous day are wet P(W|W), probability that today is wet and the previous day was dry P(W|D), probability that today is dry and the previous day was wet P(D|W), and probability that both today and previous day are dry P(D|D). Usually the definition for a wet day is that the rainfall amount exceeded 1 mm.

If a month consists of n days then there will be n-1 consecutive days in that month. Among n-1 pairs, some are W|W, W|D, D|W, and/or D|D. Suppose that $n_{w|d}$ describes the number of consecutive day where the current day is wet while the previous day was dry, then:

Estimate of $P(W|D) = \frac{n_{w|d}}{n_{w|d} + n_{d|d}}$ **[A11]**

The same principle applies for calculating P(W|W), P(D|W), and P(D|D), and:

$n_{w|w} + n_{w|d} + n_{d|w} + n_{d|d} = n-1$
$P(W|W) + P(D|W) = 1$
$P(W|D) + P(D|D) = 1$
$P(W|W) \geq P(W|D)$

Now supposed that the first day in a generated sequence is dry, then we would predict that the next day is dry if $0<r<P(D|D)$ and wet if $P(D|D)<r<1$ where r is a generated random number between 0 and 1. If the first day is wet then the next day is dry if $0<r<P(D|W)$ and it is wet if $P(D|W)<r<1$. The two-state first–order Markov chain can be expanded, e.g. up to the second or third-order to determine a rainy day. In that case, a larger transition matrix has to be produced. In the two states second-order Markov chain, there will be 2^2x2 rainfall occurrence probabilities, in the third-order 2^3x2. For these higher orders of Markov chain, the same principle applies to determine whether a day is a rainy day or not, e.g. if it happened that three consecutive days were dry, then the next day is dry if 0<r<P(D|DDD) and wet when P(D|DDD)<r<1.

For the first-order Markov chain, there is a relation between P(W|D) and f which is the average fraction of days that are wet in a month or in other words, the overall probability of a day being rainy (Geng *et al.*, 1986):

$$P(W|D) = bf \quad \textbf{[A12]}$$

They found empirically that the constant b has a value of around 0.75. f must equal the sum of the products of the two conditional probabilities and the probability of either a dry or wet day:

$$f = bf(1-f) + P(W|W)f \quad \textbf{[A13]}$$

Thus, the relation between P(W|W) and f is:

$$P(W|W) = 1 - b + bf \quad \textbf{[A14]}$$

This means that regardless the value of f, P(W|W) is always 1-b greater than P(W|D).

Remarks:
In case we only have data of the fraction of wet days in a month (i.e. f value), P(W|W) and P(W|D) can be calculated by assuming b equals 0.75 which seems to be a common value for many tested areas. If variation in rainfall occurrence is high between months, the calculation of rainfall occurrence probabilities can be done for each month.

In a multi-state Markov chain model, daily rainfall is divided into a number of states. For example, Boughton (1999) defined state 1=no rainfall, 2=0<rain<0.9 mm, 3=0.9<rain<2.9 mm, and so on up to state 6=14.9 mm<rain with no upper limit. A transition matrix will describe the probability for rain in one state to be followed by rain on the next day in the same or another state.

Determining the amount of rainfall in a wet day

The most common approach for describing the distribution of rainfall amounts on days with rain is to ignore the serial autocorrelation and consider that rainfall amounts are serially independent and to fit some theoretical distributions to the precipitation amount (Duan et al, 1995). This means we assume that precipitation amounts on subsequent rainy days are independent but that the probability of it being a rainy day may depend on the state of the previous day(s). If a day is wet then we need the second step, i.e. to estimate the rainfall amount in that day. There are many different probability distribution functions that can be used for this purpose and they are classified into single-parameter models and multi-parameter models. Some single-parameter models have been derived by calibrating multi-parameter models.

Single-parameter models

The exponential distribution is probably the most widely used single-parameter model of daily rainfall for its simplicity and relatively good fit (e.g. Richardson, 1981). Its cumulative distribution function is as follow where x is the daily precipitation, λ=E(x) is expectation of daily precipitation in a month obtained by dividing the monthly rainfall by number of wet days, and F(x) is the probability of events with rainfall amount less than x:

$$F(x) = 1 - e^{\frac{-x}{\lambda}}$$ **[A15]**

Pickering et al. (1988) calibrated the three-parameter beta-P distribution model to yield a single-parameter model as follow:

$$F(x) = 1 - (1 + \frac{x}{9\lambda})^{-10}$$ **[A16]**

A member of Weibull family of distribution can also be a single-parameter model (Rodiguez, 1977), with c as a dimensionless parameter with a value usually around 0.75 or 0.5 (Selker and Haith, 1990) and Γ is the complete (two-parameter) Gamma function:

$$F(x) = 1 - \exp\{-\left[\Gamma\left(1 + \frac{1}{c}\right)\frac{x}{\lambda}\right]^{c}\}$$ **[A17]**

If the threshold for a wet day is 1 mm, then equation 7 needs to be modified to (Scotter *et al.*, 2000):

$$F(x) = 1 - \exp\{-\left[\Gamma\left(1 + \frac{1}{c}\right)\frac{(x-1)}{(\lambda-1)}\right]^{c}\}$$ **[A18]**

It can be shown that a smaller value of c will generate more extreme rainfall events. The most important however is to correctly describe the probability of high daily rainfall events (e.g. rainfall > 20 mm). Solving equation 8 for x gives:

$$x = \left[\frac{\lambda-1}{\Gamma\left(1+\frac{1}{c}\right)}\right][1 - \ln(1-F)]^{\frac{1}{c}} + 1$$ **[A19]**

Multi-parameter models

This model type is generally considered to describe the distribution of precipitation amounts better than the single-parameter models because of greater flexibility obtained with the larger number of parameters. The 2-parameter Gamma, 3-parameter Gamma, and 3-parameter mixed exponential have been used. Richardson (1982) stated that unless the mixed exponential distribution has a clear advantage over the 2-parameter Gamma distribution, the gamma distribution is an appropriate choice of models for most applications. The general form of 2-parameter Gamma probability function is as follow:

$$f(x) = \frac{x^{\alpha-1}e^{\frac{-x}{\beta}}}{\beta^{\alpha}\Gamma(\alpha)}$$ **[A20]**

And the cumulative distribution function is:

$$F(x) = \frac{\gamma(\alpha, \frac{x}{\beta})}{\Gamma(\alpha)}$$ **[A21]**

Where $\gamma(\alpha, x/\beta)$ is the lower incomplete Gamma function. There are two ways for estimating α and β which are constant in the Gamma distribution function. The simplest but good one uses moment estimators (Devore, 1987):

$$E(x) = \alpha\beta$$ **[A22]**

$$Var(x) = \alpha\beta^2$$ **[A23]**

To estimate rainfall amount in a wet day, we again have to generate a random number between 0 and 1 and put this value equals to F (i.e. the cumulative distribution function). Equation 5 will give a value for x, i.e. the rainfall of the day according to an exponential distribution, equation 6 according to beta-P distribution, equation 9 with Weibull-type distribution, and equation 11 according to 2-parameter Gamma distribution. For equation 9, MS Excel has a GAMMALN(x) function to return a value of natural logarithm of Gamma function Γ(x). For equation 11, the function GAMMAINV (F,α,β) in MS Excel can return the inverse of Gamma cumulative distribution.

Appendix 11. Water uptake module in WaNuLCAS

Water transport from soil to leaf has to overcome resistances along the pathway (Smith *et al*., 2004). Uptake of water is compatible with the physical reality of driving forces (gradients in water potential) and resistances in the path: bulk soil – rhizosphere – root – leaf – atmosphere (De Willigen et al., 2000). When plants open the stomata, a negative water potential in the leaves can generate flow of water towards the leaves from all layers of soil where the plant has roots and where the water potential in the soil is less negative than that in the plant. Water transport can be modeled as an Ohm's law analogue and requires the calculation of gradients in water potential and conductivity (the inverse of resistance) on different sections along the pathway. The water uptake module only pertains to a part of the path, i.e. the transport of water from bulk soil to stem base. Below is a description of modeling water uptake in the WaNuLCAS model.

I. Plant level

The calculation of water potential and transport is done at voxel and plant level. Voxel-level calculation involves roots and water inside the voxels only, whereas plant-level calculation integrates uptake and transport over rooted voxels.

1. Soil water potential perceived by plant (Ψ^{sp}, cm)

$$\Psi^{sp} = -\left(\frac{\sum_i Lrv_i * v_i}{\sum_i Lrv_i * v_i * \left|\Psi_i\right|^{-d}}\right)^{1/d} \quad \textbf{[A24]}$$

Where:
Lrv_i = root length density in voxel i (cm cm^{-3})
v_i = voxel volume (cm^3)
Ψ_i = soil water potential in voxel i (cm)
d = indicates the relative influence of dry voxels ('drought signal') on the calculation of Ψ^{sp}. When d=1, we use a harmonic average (dimensionless). The lower the value of d the more negative Ψ^{sp} and the lower the transpiration demand due to the closure of stomata.

Ψ^{sp} should be between the Ψ of driest and wettest soil. The resulting unit = cm cm^{-3} * cm^3 / (cm cm^{-3} * cm^3 * cm-1) = cm

2. Rhizosphere potential (Ψ^{rhizp}, cm)

$$\Psi^{rhizp} = \Psi^{sp} * (1 + b) \quad \textbf{[A25]}$$

Where:
b = buffer potential: potential drop needed for water to move from bulk soil to the root surface (in the rhizosphere), here expressed as a fraction of Ψ^{sp} (%)

3. Potential gradient for uptake (radial transport into roots) (Ψ^{radp}, cm)

$$\Psi^{radp} = \frac{-E^{pot} * 0.1}{K^{rad} * Lra}$$ **[A26]**

Where:
E^{pot} = potential transpiration demand (liter m^{-2} or mm). In the WaNuLCAS model (Van Noordwijk *et al.*, 2004), E^{pot} is calculated as light intercepted by plant * dry matter production per unit light interception * water use efficiency (or water use per unit dry matter production). E^{pot} is an input value of the water uptake module.
K^{rad} = radial conductivity: the inverse of resistance involved in radial movement of water from the root surface to xylem per unit gradient in water potential and per unit path-length (cm^3_{water} $cm^{-1}_{gradient\ of\ water\ potential}$ $cm^{-1}_{root\ length}$)
Lra = total root length per unit soil surface area (cm cm^{-2})

The resulting unit = mm * 0.1 / (cm^3 cm^{-1} cm^{-1} * cm cm^{-2}) = cm

4. Potential gradient for longitudinal transport in roots (Ψ^{longp}, cm)

$$\Psi^{longp} = -E^{pot} * \frac{\sum_i L_i * Lrv_i * v_i}{\sum_i Lrv_i * v_i} * R^{longsap}$$ **[A27]**

Where:
L_i = distance from voxel midpoint to soil surface (stem base) (m)
$R_{longsap}$ = longitudinal resistance factor for root sap (root to stem base): gradient in water potential per unit water demand per unit path-length ($cm_{gradient\ of\ water\ potential}$ $mm^{-1 water\ demand}$ m^{-1}_{soil})

The resulting unit = mm * (m * cm cm^{-3} * cm^3 / cm cm^{-3} * cm^3) * cm mm^{-1} m^{-1} = cm

5. Initial estimate of required plant water potential (Ψ^{lrepq}, cm) to meet the potential transpiration demand

$$\Psi^{reqp} = \Psi^{rhizp} + \Psi^{radp} + \Psi^{longp} = \Psi^{sp} * (1+b) + \Psi^{radp} + \Psi^{longp}$$ **[A28]**

It can be noted that, only Ψ^{radp} and Ψ^{longp} are a function of Epot. Ψ^{rhizp} is independent on transpiration demand. On the other hand, the former two are not dependent on soil water condition.

II. Plant level (reduced transpiration demand)

The actual transpiration is assumed to be a function of the potential transpiration demand (that depends on 'external' environmental factors only) and the plant water potential.

6. Campbell reduction factor for transpiration (f, dimensionless) is calculated from a sigmoid-type function.

$$f = \frac{1}{1+\left(\frac{\Psi_{reqp}}{\Psi_{0.5}}\right)^{a}}$$ **[A29]**

$$a = \frac{2 * \ln\left(\frac{\alpha}{1-\alpha}\right)}{\ln\left(\frac{\Psi^{transp}_{max}}{\Psi^{transp}_{min}}\right)}$$ **[A30]**

Where:
$\Psi_{0.5}$ = plant water potential where transpiration is half of its potential value (cm)
a = Campbell factor (dimensionless)
α = a small value (dimensionless, default is 0.1)
Ψ^{trasp}_{max} = plant water potential when f is at (1 - α) (cm)
Ψ^{trasp}_{min} = plant water potential when f is at α (cm)

Because:

$$1-\alpha = \frac{1}{1+\left(\frac{\Psi^{transp}_{max}}{\Psi_{0.5}}\right)^{a}}$$ **[A31]**

And:

$$\alpha = \frac{1}{1+\left(\frac{\Psi^{transp}_{min}}{\Psi_{0.5}}\right)^{a}}$$ **[A32]**

Then:

$$\Psi_{0.5} = -\sqrt{\Psi^{transp}_{max} * \Psi^{transp}_{min}}$$ **[A33]**

7. Reduced plant transpiration demand and water potential

$$E^{red} = E^{pot} * f \qquad \textbf{[A34]}$$

$$\Psi^{redreqp} = \Psi^{rhizp} + \left(\Psi^{radp} + \Psi^{longp}\right) * f \qquad \textbf{[A35]}$$

Recalling that only Ψ^{radp} and Ψ^{longp} are a function of E^{pot}, Ψ^{rhizp} is independent on transpiration demand.

III. Voxel level

Water uptake by the root system is 'scaled-up' from the calculation of water uptake for a single root. This has been described in e.g. De Willigen *et al*. (2000), De Willigen and Van Noordwijk (1987, 1995), Heinen (2001), and Personne *et al*. (2003).

8. Voxel rhizosphere water potential$_i$ (Ψ^{rhiz}_i cm)

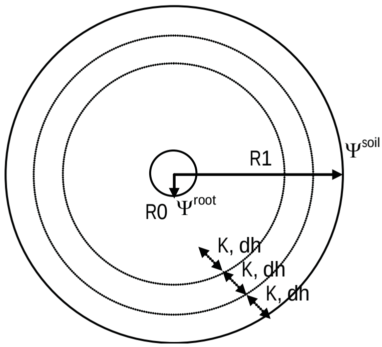
$$\Psi_i^{rhiz} = \Psi^{redreqp} - \frac{L_i}{\left(\dfrac{\sum_i^n L_i * Lrv_i * v_i}{\sum_i^n Lrv_i * v_i}\right)} * f * \Psi^{longp} \qquad \textbf{[A36]}$$

The resulting unit = cm – (m * m^{-1}) * cm = cm

In other words, the plant water potential at stem base applies for L_i = 0. The equation shows that Ψ^{rhiz}_i reflects the potential needed for water transport from the soil towards root surface and that required for water to flow to root xylem.

9. Potential water transport$_i$ (T^{pot}_i, mm)

This should be understood as flow of water from the bulk of soil towards root surfaces. For this, we need information of pressure head difference, water conductivity across the bulk soil (i.e. strongly dependent on soil characteristic) and path length. The flow equations for soil water transport are however highly non-linear (De Willigen *et al*., 2000) due to the non-linear relationship between water content and potential, and conductivity is decreasing strongly with decreasing pressure head. Consider the following figure that illustrates 'space grids' for soil-root radial transfer within soil cylinder:



Roots are assumed to be vertically oriented and regularly distributed in the voxel. Root is regarded to be a cylinder shape situated within soil cylinder. The bulk soil of the voxel is then divided into uniform (i.e. the same size) vertical soil cylinders with single root inside each of them. Water transport for single root only occurs between the inner boundary (root surface) and the outer boundary (i.e. soil cylinder). R0 is the root radius (cm) and R1 is the radius of soil cylinder (cm) that depends on root length density in the voxel:

$$R1 = \frac{1}{\sqrt{\pi * Lrv}}$$ **[A37]**

Water potential at the root surface (root-soil contact) is the voxel rhizosphere water potential (Ψ_{root}), at the bulk soil (i.e. at the outer boundary) is the soil water potential (Ψ_{soil}). Soil is usually drying closer to the root surface. Therefore, Ψ_{soil} and conductivity should be calculated for each 'space grid' (where linearity could be assumed) along bulk soil-root path. Because root is vertically oriented within soil cylinder, only radial water transport to root surface is taken into account. For horizontal transport, the non-linearity of the flux can be removed by introducing the matric flux potential (De Willigen et al., 2000):

220

$$\Phi = \int_{h_{ref}}^{h} K * dh$$ **[A38]**

Where Φ is the matric flux potential (cm^2 day^{-1}), h_{ref} is a reference value of the pressure head (cm), and K is water conductivity (cm day^{-1}). For the water flux from soil towards the root surface (i.e. for condition that $\Psi_{root} < \Psi_{soil}$ for the transport to occur):

$$\Delta\Phi = \int_{h^{root}}^{h^{soil}} K * dh = \int_{h^{ref}}^{h^{soil}} K * dh - \int_{h^{ref}}^{h^{root}} K * dh = \Phi^{soil} - \Phi^{root}$$ **[A39]**

In the WaNuLCAS model, for a discretisation of the integral, h_{ref} is obtained at pF = 6 and the 'space grids' pertain to 0.1 intervals of pF down to pF^{soil} and pF^{root}:

$$h(pF) = -10^{pF}$$ **[A40]**

$$K(h) = K_{sat} * \frac{\left(\left(1+\left|alpha*h\right|^{n}\right)^{1-\frac{1}{n}} - \left|alpha*h\right|^{n-1}\right)^{2}}{\left(1+\left|alpha*h\right|^{n}\right)^{\left(1-\frac{1}{n}\right)*(\lambda+2)}}$$ **[A41]**

$$\Phi_i^{soil} = \sum_{j=pF_i^{soil}}^{j=pF^{ref}} [(K(h(j)) + K(h(j+0.1))] * 0.5 * (h(j) - h(j+0.1))$$ **[A42]**

$$\Phi_i^{root} = \sum_{j=pF_i^{root}}^{j=pF^{ref}} [(K(h(j)) + K(h(j+0.1))] * 0.5 * (h(j) - h(j+0.1))$$ **[A43]**

Where alpha, K_{sat}, λ, n are Van Genuchten parameters. $\Delta\Phi$ reflects water flow per unit area of root surface. 'Scaling up' to a root system requires information of R0 and R1 to consider the circumference of root and soil bulk cylinder, and of root length density. The steady rate solution to the flow problem (i.e. the same flux rate to root surface regardless of the depth of the root segment in the voxel) and assuming that all roots have a good contact with soil, is assumed to be the potential water transport from soil to roots in the voxel (mm day^{-1}) (Heinen, 2001; De Willigen and Van Noordwijk, 1995):

$$T_i^{pot} = \frac{\pi * \Delta z_i * Lrv_i * (\Phi_i^{soil} - \Phi_i^{root}) * \left(\rho_i^2 - 1\right) * 10^3}{G_0(\rho_i)}$$ **[A44]**

$$G_0\left(\rho_i\right) = \frac{1}{2}\left(\frac{1-3\rho^2}{4} + \frac{\rho^4 \ln(\rho)}{\rho^2 - 1}\right)$$ **[A45]**

$$\rho_i = \frac{R1_i}{R0}$$ **[A46]**

Where Δz is the voxel thickness (m). It can be noted that $\Delta\Phi$ should be multiplied by total root length (i.e. Lrv * voxel volume) to get the volume of water flow (cm^3). Division by voxel surface area results length of water and thus only the voxel thickness is included in the equation. Now suppose we have two types of plant (model extension into several plants is surely possible): weak (i.e. with less negative plant water potential) and strong plant, and assume $\Phi^{soil} > \Phi^{weak} > \Phi^{strong}$. Water flux for weak and strong plant (say 'common range') is Φ^{soil} - Φ^{weak} and exclusively for strong plant ('exclusive range') is Φ^{weak} - Φ^{strong}. The potential water transport of weak and strong plant in the voxel is calculated as follow:

For weak plant:

$$T_i^{potweak} = \frac{\pi * \Delta z_i * Lrv_i^{weak} * (\Phi_i^{soil} - \Phi_i^{weak}) * \left((\rho_i^{com})^2 - 1 \right) * 10^3}{G_0(\rho_i^{com})}$$ **[A47]**

$$\rho_i^{com} = \frac{R1_i^{com}}{R0_i}$$ **[A48]**

$$R1_i^{com} = \frac{1}{\sqrt{\pi * (Lrv_i^{weak} + Lrv_i^{strong})}}$$ **[A49]**

$$D0_i = \left(\frac{Lrv_i^{weak} * \sqrt{D0^{weak}} + Lrv_i^{strong} * \sqrt{D0^{strong}}}{Lrv_i^{weak} + Lrv_i^{strong}} \right)^2$$ **[A50]**

$$R0_i = \frac{D0_i}{2}$$ **[A51]**

For strong plant in the common range:

$$T_i^{potstrong} = \frac{\pi * \Delta z_i * Lrv_i^{strong} * (\Phi_i^{soil} - \Phi_i^{weak}) * \left((\rho_i^{com})^2 - 1 \right) * 10^3}{G_0(\rho_i^{com})}$$ **[A52]**

And for strong plant in the exclusive range:

$$T_i^{potstrong} = \frac{\pi * \Delta z_i * Lrv_i^{strong} * (\Phi_i^{weak} - \Phi_i^{strong}) * \left((\rho_i^{ex})^2 - 1 \right) * 10^3}{G_0(\rho_i^{ex})}$$ **[A53]**

$$\rho_i^{ex} = \frac{R1_i^{ex}}{R0_i}$$ [A54]

$$R1_i^{ex} = \frac{1}{\sqrt{\pi * Lrv_i^{strong}}}$$ [A55]

(As said before, the described modeling of potential transport is actually limited to the case where roots are regularly distributed and vertically oriented with a complete root-soil contact. For the time being, it also approximates potential transport in a more complex situation, i.e. non-regularly distributed and parallel roots or non-regularly distributed and non-parallel roots either with complete or non-complete root-soil contact whilst maintaining model simplicity (Van Noordwijk, personal communication). However, complete soil-root contact along the whole length of a root may be the exception rather than the rule (De Willigen and Van Noordwijk, 1987). Due to the assumptions, water transport potential is usually non-limiting (see below) for the actual water uptake).

10. Available water for uptake (θ_i, mm)

Available water in the common and exclusive range respectively are:

$$\theta_i^{com} = \left(\theta_i^{soil} - \theta_i^{weak}\right) * \Delta z_i * 10^3$$ [A56]

$$\theta_i^{ex} = \left(\theta_i^{weak} - \theta_i^{strong}\right) * \Delta z_i * 10^3$$ [A57]

Following Van Genuchten:

$$\theta_i^{soil} = \frac{\left(\theta_i^{sat} - \theta^{residual}\right)}{\left(1 + \left|alpha_i * \Psi_i^{soil}\right|^{n_i}\right)^{1 - 1/n_i}} + \theta^{residual}$$ [A58]

Where Ψ^{soil} is replaced by Ψ^{weak} and Ψ^{strong} to calculate θ^{weak} and θ^{strong} respectively. In the common range, water is shared between the weak and strong plant proportional to their root length density. Next is the calculation for weak plant with the same principle applies for strong plant:

$$\theta_i^{comweak} = \frac{Lrv_i^{weak}}{Lrv_i^{weak} + Lrv_i^{strong}} * \theta_i^{com}$$ [A59]

11. Adjusted water transport potential (T^{adjpot}_i, mm)

Water uptake is limited either by transport or water available for uptake. The minimum of the two say 'adjusted water transport potential' is then (calculated for the weak and strong plant in the common range, and for strong plant in the exclusive range):

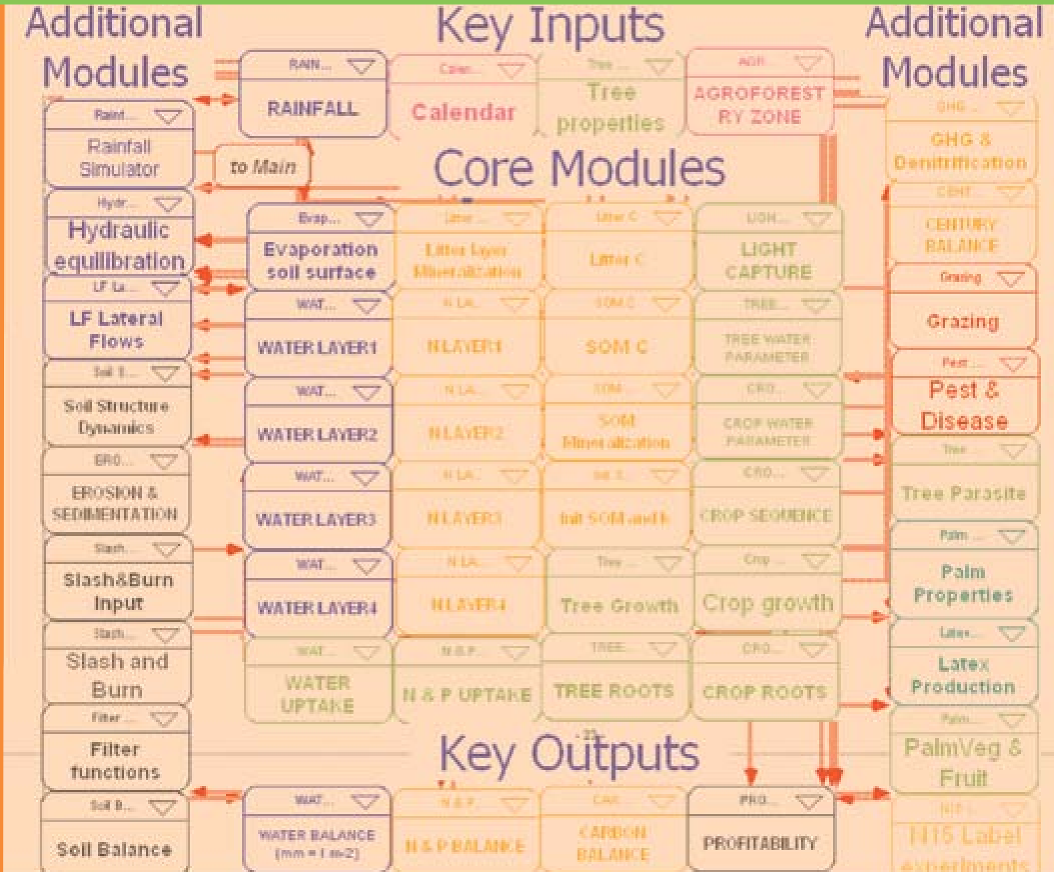
$$T_i^{adjpot} = \min\left(T_i^{pot}, \theta_i\right)$$ **[A60]**

12. Actual water uptake$_i$ (S_i, mm)

(The following calculation applies for the weak and strong plant)

If $\sum_i T_i^{adjpot} \leq E^{red}$ then $S_i = T_i^{adjpot}$ else **[A61]**

$$S_i = \frac{T_i^{adjpot}}{\sum_i T_i^{adjpot}} * E^{red}$$ **[A62]**



World Agroforestry Centre

TRANSFORMING LIVES AND LANDSCAPES