Forest, Agroforest, Low-value Land Or Waste?

FALLOW 2.0

Manual and Software

Desi Ariyadhi Suyamto, Rachmat Mulia, Meine van Noordwijk and Betha Lusiana

World Agroforestry Centre

Forest, **A**groforest, **L**ow-value **L**and **O**r **W**aste?

FALLOW 2.0
Manual and Software

... A tool to help you illuminating future options on development strategies to transform your rural agricultural landscapes into places worth living in and worth fighting for...

Desi Ariyadhi Suyamto, Rachmat Mulia,
Meine van Noordwijk and Betha Lusiana

World Agroforestry Centre

Correct citation

Suyamto D, Mulia R, van Noordwijk M, and Lusiana B. 2009. FALLOW 2.0 Manual and Software. World Agroforestry Centre, Bogor, Indonesia. 67p.

ISBN:

979-3198-44-6

Disclaimer and Copyright

This is a model on dynamics of the rural landscape. Although efforts have been made to incorporate relevant process knowledge on a range of interactions, the model is not more (and not less) than a research tool. Model outputs are 'prospectives' ('looking ahead', 'plausible futures') that may help in developing specific hypotheses for research, in exploring potential future options on development strategies, but they should not be used as authoritative statements or 'predictions' per se.

Copy right, but do not copy wrong. The FALLOW model was developed on the basis of publicly funded research at the World Agroforestry Centre (ICRAF) and may be used for non-commercial research purposes in the interest of research or governmental institution as well as farmers of the world.

For further information, consultation, and technical support please contact:

Desi Ariyadi Suyamto (dsuyamto@gmail.com, d.suyamto@cgiar.org),
Rachmat Mulia (r.mulia@cgiar.org), or
Meine van Noordwijk (m.van-noordwijk@cgiar.org)

World Agroforestry Centre
ICRAF Southeast Asia Regional Office
Jl. CIFOR, Situ Gede, Sindang Barang, Bogor 16115
PO Box 161, Bogor 16001, Indonesia
Tel: +62 251 8625415; fax: +62 251 8625416
Email: icraf-indonesia@cgiar.org
http://www.worldagroforestry.org/sea

Design & layout:
Josef Arinto

Cover Design:
Degi Harja

Cover photo story:

Pak Dahlan of Seunebok Tengoh Village in Aceh Barat District is one of the farmers who have research-cum-demonstration plots of mixed rubber agroforests. The improved agroforests are more productive and profitable than traditional agroforests. The ecological and economic data gathered from these plots are used in FALLOW simulation that can provide prospective information on the impact of land use strategies. Pak Dahlan is pleased to be part of this action research.

2009

Acknowledgment

The current development of the FALLOW Model was funded by EU under ReGrIn Project, in co-cooperation with Hohenheim University, Stuttgart, Germany. Thanks to Dr. Laxman Joshi, Ery Nugraha, Fery Johana and Janudianto (World Agroforestry Centre) who support the model application and dissemination in Meulaboh, Aceh. Also thanks to Prof. Georg Cadisch, Dr. Thomas Hilger and Dr. Carsten Marohn (Hohenheim University) who connect the model to the students.

Table of Content

1. FALLOW output as field guide to the future

According to Chomitz (2007) one billion people in developing countries rely heavily on forests for their livelihoods (and a quarter of a billion on savanna systems) but only 11% of them live in 'core forest' areas (36% of the area, 13 persons km^{-2}), 36% live in 'forest edges' (36% of the area, 44 persons km^{-2}) and 53% in 'mosaic lands' of forest + agriculture (28% of the area, 85 persons km^{-2}). Rural livelihoods in many landscapes depend on a combination of forest products and agriculture. Balancing these two components is needed for development (Tomich et al., 2001).

Development means change; hopefully change for the better. There is no agreement, however, on how 'better' can be measured. Grossly simplifying, we can see change in economical and ecological values of a landscape, as a result of change in land use practice. Figure 1 describes four possible directions that a particular development strategy might lead the current condition. 'Conservation' and 'Red development' bring improvement in ecological and economical aspect respectively. 'Green development' enhances both, while 'Collapse' decreases both.

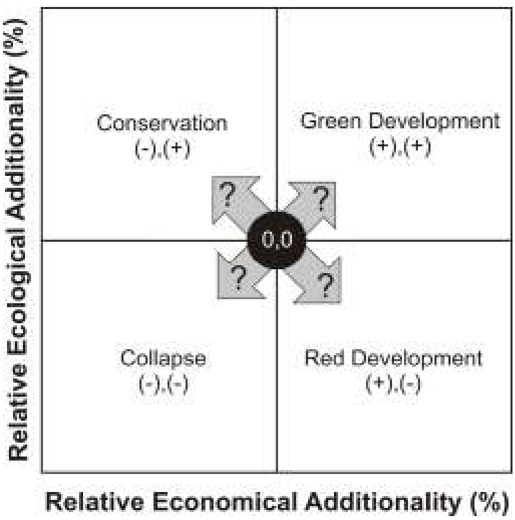


Figure 1. Positive or negative change in economic (x-axis) and ecological (y-axis) value relative to initial condition defines four quadrants; a 'Conservation' strategy will likely reduce economical value, in contrast to a 'Red development' strategy that compromises ecological value; 'Green development' strategies increases both economical and ecological value, while 'Collapse' leads to decline in both

Landscape transformations affect the lives of people ('farmers') both through changes in 'flows' (such as yield, income or expenditure) and changes in 'stocks' (such as parts of natural, human, social, financial or physical capital). Changes in stocks can have 'knock-on' effects and consequences for many years. A typical dilemma is the short-term gain in benefits at the long-term cost of reducing natural capital. 'Meeting current needs without compromising options for the future', as one of the many sustainability definitions suggests, is easily formulated in general, but needs to be made specific to the context of a landscape and the options it provides, before it is operational. Farmers, as direct managers of landscapes, and the next-level of landscape managers who try to influence (regulate, stimulate) what farmers do (or don't do), need ways to 'prospect', or look ahead, before implementing a strategy to their landscape. Such a 'prospective' needs to provide a description of possible and plausible changes in ecological and economic values that might be triggered or caused by a certain strategy. They need a 'tool' that can provide prospective information, based on which, sensible development strategies can be formulated and implemented.

A mechanistic model to simulate land cover change and landscape transformation in agricultural/forest margin rural areas should consider, at least, these three following aspects:

- Farmers are the main actors that induce land cover change. The model should therefore simulate the processes of decision-making by farmers (collectively and/or individually) as response to farmers own observations and evaluation of various external conditions, either directly or mediated through the ways other stakeholders have to influence farmers decisions ('carrots, sticks or sermons').
- Growth and succession of vegetation and land cover types, and decisions made by farmer or community on change in land cover types will result in a spatial and temporal dynamic of the landscape that feeds back on the opportunities for further change. The model should be able to explicitly visualize both the spatial and temporal dynamic and to deal with key feedbacks from spatial 'pattern' towards temporal 'process'.
- The impacts of a certain development strategy need to be measured in at least two dimensions (as in Figure 1) as the way economical and ecological value change relative to initial condition. To provide an overview of the complexity, the model should provide quantitative but comprehensive economical and ecological indicators.

The FALLOW (**F**orest, **A**groforest, **L**ow-value **L**ands **O**r **W**aste) model is a simulation model that provides prospective information on the impact of a development strategies (modified incentives, knowledge, restrictions and rules) applied in a rural agricultural landscape. It covers the three attributes just mentioned and can be used as a tool to prospect to which direction a certain strategy will lead the farmer society, to a ruin ('Collapse'), win-win outcome ('Green development'), or simple tradeoff (win-loose)_between 'Conservation' and 'Red development', An overview of the model concept is given in chapter 2, followed by a 'hands-on' instruction how to get outputs from the model and how to modify the inputs. Examples of model specifications for certain landscapes and of the way the model has so far been used are provides in a number of figures and tables. Further examples can be found on the Fallow Model website.

Before we start with the model as such, it may be good to reflect on the modellers' own strategy (van Noordwijk, 1996):

“Don't believe the models you will see,
unless the data agree,

Don't believe your data again,
unless new models explain,

However, suspicion will be on you,
if agreement is 'too good to be true'.

Be prepared, though, for the politician's mood,
that conclusions are 'too true to be good'. “

2. FALLOW model concepts

The current version of the FALLOW model has grown out of a simple spatial representation of the transition of 'shifting cultivation' into 'crop/fallow' and permanent cropping systems, building on a model first formulated by Trenbath (van Noordwijk, 1999). The core modules of the model referred to ***plots*** (with changes during a year involving crop yield, biomass growth, increase or decrease of soil fertility), ***households*** (with harvest of main staple above or below food requirement, depleting or replenishing food stocks), farmer decision making on land use intensity (increasing or decreasing the area opened for a next cropping phase), based on ***current farmer knowledge and expected yields*** and ***spatial prioritization*** (selecting those plots in the landscape for cropping that are most convenient, within existing restrictions of access to parts of the landscape). These four core modules, that are still at the heart of the model, make use of a number of modules which process input data for the dynamic part and feed a number of modules that translate the dynamic of the landscape to output parameters (van Noordwijk, 2002).

The current version of FALLOW has much stronger visualization of the spatial properties, can handle much larger landscapes, more diverse land use options, transitions towards full market integration, and richer dynamics of local knowledge, but the basic concepts are still recognizable. The model operates on yearly time-step to reflect 'strategic' decision making by farmers, rather than the 'tactical' allocations of resources at a daily (or weekly) time step. The impacts of land cover changes on landscape functionality (from an economical or biophysical perspective) may be adequately covered by a yearly time step.

The model simulates farmers as collective and not on individual/household basis in a rural landscape. However, within this community, variation can exist in decision making based on different ways of interpreting experience. The interactions between two types of farmers can be simulated: 'conservative' farmers who take a 'wait and see' approach to new land use options, and 'experimental' farmers who are more inclined to try new options based on external information. In the face of new options, these two types of farmers pursue distinct development strategies.

As mentioned before, the model regards farmers as the main actors and decision makers, but it can explore higher level decision makers who can change prices, external sources of knowledge, physical and/or institutional access to parts of the landscape. The learning and decision-making by the farmers is thus the heart of the model. The following issues are at stake:

- How to allocate the resources (labour, financial capital, and land) in hand over the various livelihood options available (using the farm, the surrounding landscape, off-farm within landscape or out-of-landscape options)?
- How to adjust their expectation on food and/or financial returns-to-labour for the next decision cycle based on the current results for the landscape?
- On which plots will the land cover change be implemented?

Farmers can make decision related to the above queries only after considering biophysical or socio-economic aspects. For the first and the second, they may have to take into account, e.g. the current growth of vegetation or more direct measures of soil fertility, ecological stage of succession and/or productivity level of their plots as well as the availability of any subsidy from the government for certain land use systems. For the third, considerations of spatial aspects need to estimate the potential benefit and cost of using the plots, as well as plot susceptibility to fire accident are necessary.

Some 'external' factors which influence the biophysical or socio-economic condition are not explicitly stated in the model, but their effect can be simulated by modifying the value of certain parameters, for example:

- Market mechanism is represented by commodity price and price differential between buying and selling the basic staple.
- Changes in government regulation or intervention can be translated into change in e.g. investment cost.
- Improvement in agronomical technique can be introduced by modifying the level of land productivity.
- Improvement in harvesting technique can relate to labour requirement per land use type, influencing labour productivity.
- Environmental conservation program is translated as the delineation of certain areas to be protected and prohibited for any (or selected) agricultural activities.

The effectiveness of a certain development strategy is reflected by how far it brings economical and ecological benefits. The first describes farmers' welfare and here is assumed to be represented by two variables: level of *food stock* and their *secondary consumptio*n (i.e. consumption beyond primary food requirements). The second describes environmental service and also reflected by two variables: *aboveground carbon stock* and *biodiversity*. A more detailed description of model's concept is given in the appendixes. The model can be coupled to a water balance model (GenRiver) that operates at a daily time step to derive specific indicators of watershed function.

3. Examples of model application

3.1 Which development strategy is most appropriate: genuine or pseudo development?

A number of applications have been developed for landscapes where an increase in landscape-level carbon stock is of interest, by planting trees and/or maintaining soil carbon stocks. Two approaches for increasing tree-based land use are: '***projects***' (temporary, spatially explicit change in economic relations), or '***programmatic approach***', with free decision making and changes in generic properties that apply throughout.

A project-approach is usually characterized by top-down incentives, applied only in the previously-determined project area and duration without any substantial effort to solve the apparent problems experienced by the society in the observed area. A programmatic-approach has more intentions to overcome the apparent problems which relate to e.g. access to market, to land, or to source of knowledge or information. We compared the results for four areas in Indonesia where 'Clean Development Mechanism' (CDM) was proposed (Fig. 2)

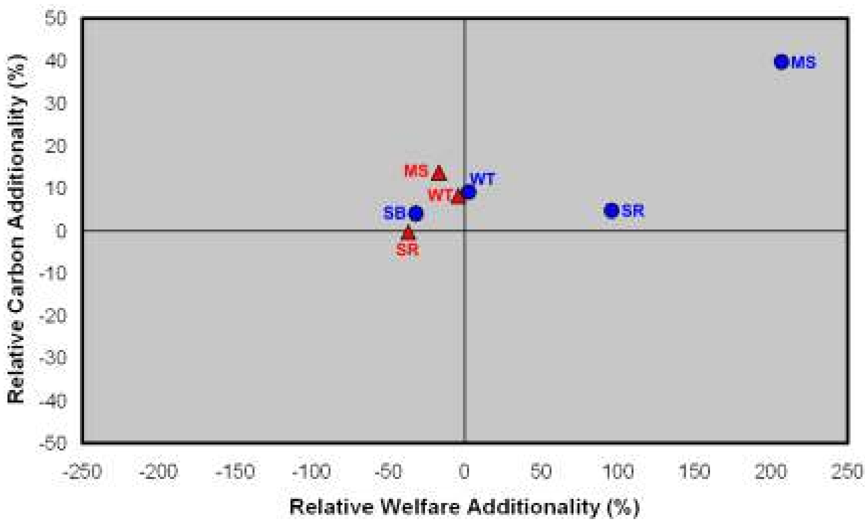


Figure 2. FALLOW model as applied in 4 regions in Indonesia: Muara Sungkai (MS) and Way Tenong (WT) in Lampung, Sumatra; Sindenreng Rappang (SR) in South Sulawesi; dan Sebuku (SB) in West Kalimantan.

Model applications in four regions in Indonesia (Figure 2) showed that a programmatic-approach (blue circles) induced the development of tree-based land use systems by farmers and can likely convert marginal lands with relatively low investment cost. This offers better economical (x axes) and ecological (y axes) merit than project-approach (red circle). The project-approach mostly induced ecological benefit, but was inferior in economical value. Please see van Noordwijk et al. (2008) for a more detailed description and explanation.

3.2 S-curve story of subsidy for development

The model has also been applied to simulate the effect of subsidy expected to accelerate the conversion of pioneer forest (i.e. marginal lands with shrubs) to rubber-based land use systems in Muara Sungkai, Sumatra. Without any subsidy, it is unlikely that this region could be converted into a landscape with prevailing rubber-plantations, as there is little capital for local investment in the 'waiting period' for newly planted rubber to become productive. The results suggest, however, that prolonged subsidy is no longer efficient in influencing land cover change when land and labour availability, rather than financial capital, become limiting (Figure 3-6) (Suyamto et al., 2005).

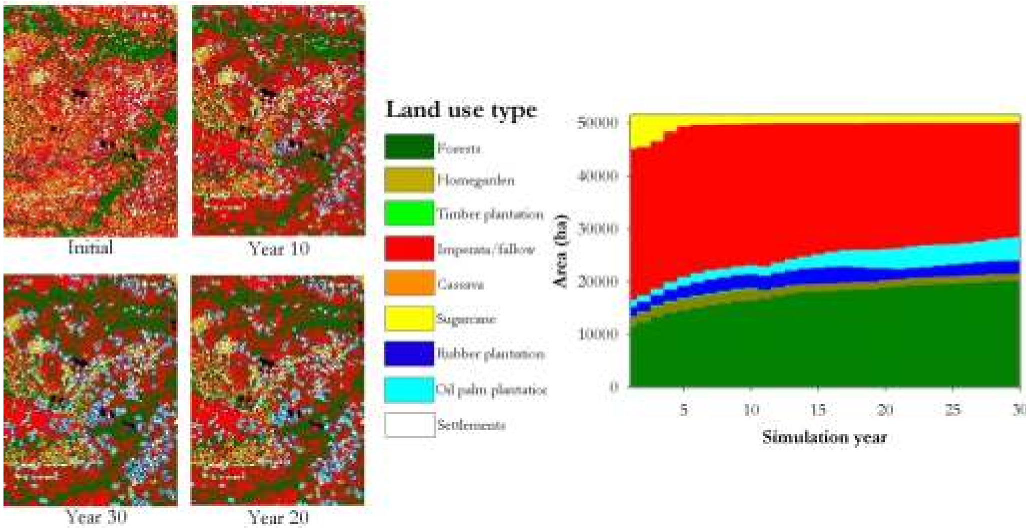


Figure 3. Land cover dynamics without any subsidy for development of rubber-based landuse system.

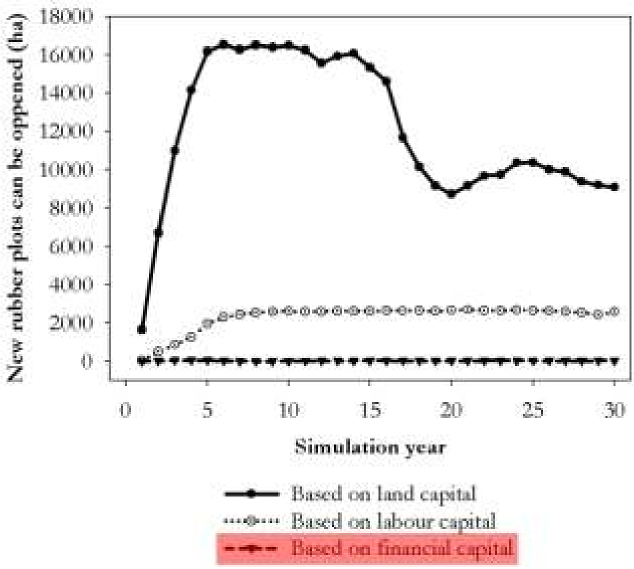


Figure 4. Limiting resources in the development of rubber-based land use system without subsidy.

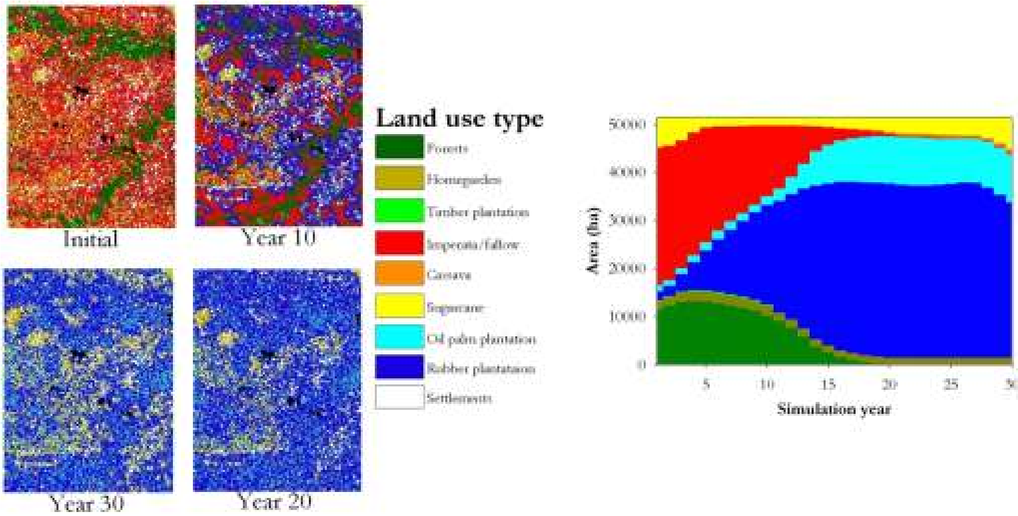


Figure 5. Land cover dynamic with subsidy for the development of rubber-based land use system.

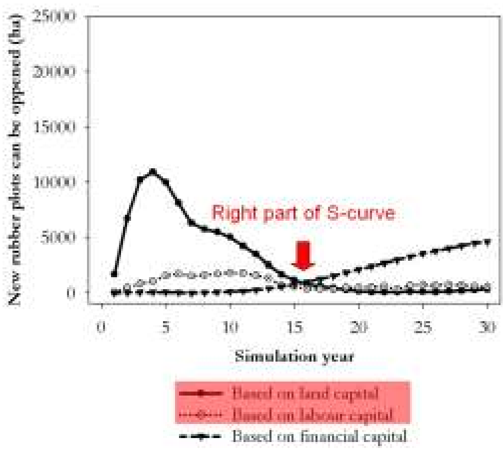


Figure 6. Limiting resources in the development of rubber-based land use system with subsidy.

4. FALLOW user guide

4.1 Specification

- FALLOW is a spatially-explicit model, raster-based with spatial resolution of 1 ha, temporal resolution of 1 year, and socio-economic resolution at community scale.
- It uses PCRaster (freely downloaded from http://pcraster.geo.uu.nl/pcrwin32/index.html) as the main platform.
- It can well operate with processor Intel Pentium 1.4 GHz, 512 MB RAM, 15 GB empty space in the hardisk, and Microsoft Windows XP Professional.

4.2 PCRaster installation

- You firstly have to download and install this platform, and save it in a certain directory, e.g. **C:\Program Files\PCRaster**
- For a free execution of PCRaster commands from any directory, you have to add the following instruction line in C:\autoexec.bat:

  Set Path=location of your PCRaster program

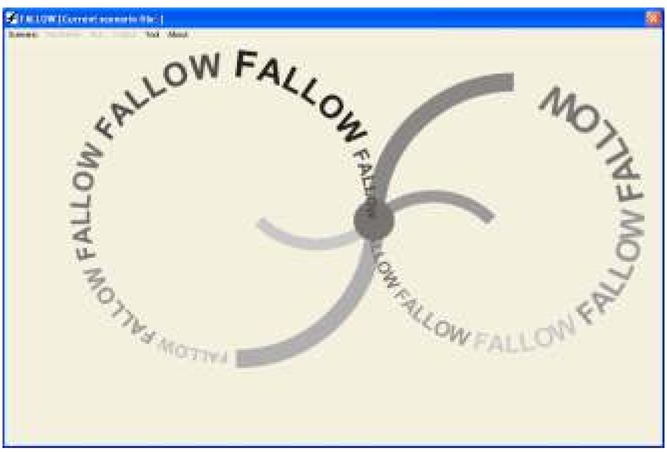
  For example, if you put the program in **C:\Program Files\PCRaster\Apps**, the appropriate instruction is: **Set Path=C:\Program Files\PCRaster\Apps**
- Please restart your computer to activate the new instruction.

4.3 FALLOW installation

- You usually obtain FALLOW as zipped file. Please extract it into a new directory, e.g. **D:\FALLOW**
- Try to find FALLOW.EXE (create a shortcut in the desktop for a convenience) and click it to run the model.

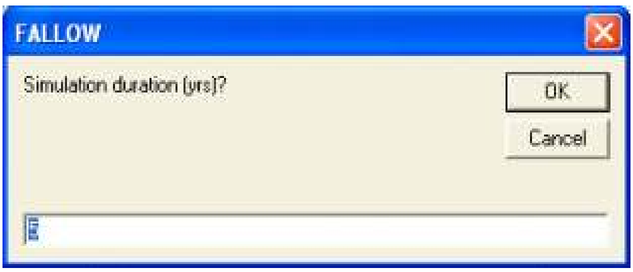
4.4 Model running with default scenario

- FALLOW user interface is designed (with Visual Basic) to help you building a scenario. Here, a scenario means a set of model parameters.

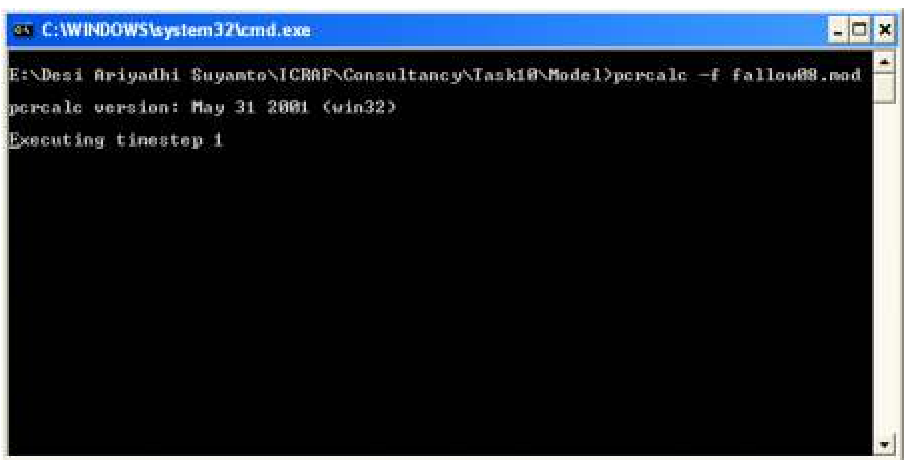


- Please select the menu **Scenario, Open**, and you will be asked to open a scenario (***. DAT**). We provide **arongan.dat** that consists of parameters for Arongan Lambalek, Aceh Barat, Sumatra, Indonesia.

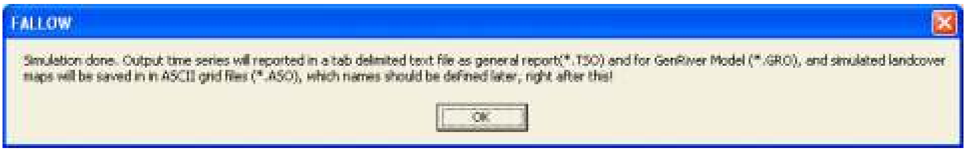
- Please select the menu **Run**, to run the scenario.
- You will be asked to determine the duration of simulation (in year). Please insert an integer in the apparent dialog box and click **OK**.



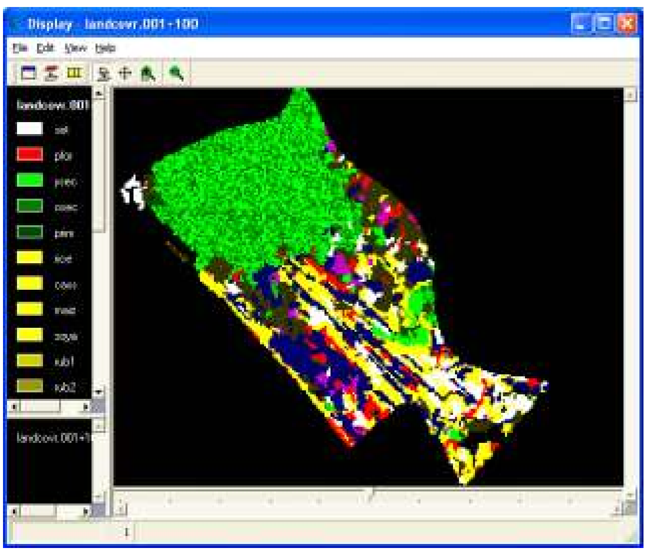
- Simulation process is displayed in MSDOS window that automatically appears after you have specified the duration of simulation. The apparent message **Executing time step** signifies a successful running…



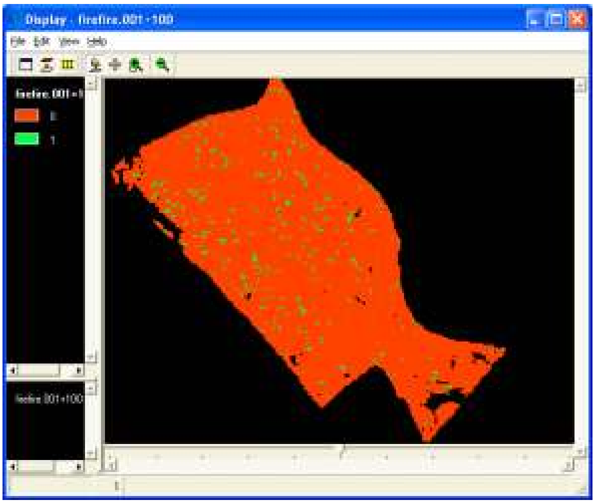
- At the end of simulation, a message box will appear asking you to give a name for three kinds of simulation report. Click **OK**.



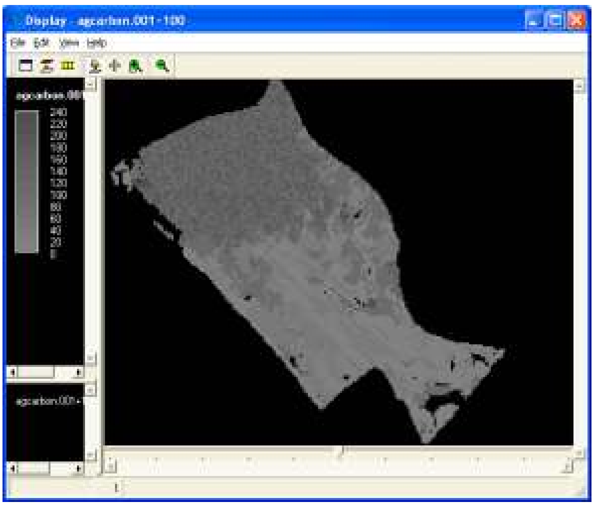
- The first kind contains simulation result in the form of time series, in the mode of **tab delimited text file**. This report type will be named with a specific extension ***.TSO**. You can open this file using **MS Excel** in **tab delimited** mode.
- The second report file containing stack of simulated outputs time series, in **tab delimited text file**, containing land use/cover change time series for the input of river flow model, i.e. **GenRiver**. The program will automatically give specific file name extension: ***.GRO**. The outputs will be stacks of land use/cover change time series file from each subcatchment. For example, if the prefix of the filename is **genriver**, and you have **5 subcatchments** in the landscape, you will find the following files: **genriver1.aso, genriver2.aso, genriver3.aso, genriver4.aso** and **genriver5.aso**. You can open this file using MS Excel in tab delimited mode.
- The third type is raster file of land cover distribution, in **generic ASCII grid**. This output will be saved in a specific extension *.ASO. You can display the data by GIS software, e.g. ILWIS or ArcView. You will find land cover data for each simulation year in your FALLOW directory. For example, if your prefix of the raster file is land cover, and simulation time is 5 years, then you will find raster files with the following names: **landcover001.aso, landcover002.aso, landcover003.aso, landcover004.aso**, and **landcover005.aso**.
- Simulation results in the form of maps can be seen through the menu **Output**.
- Please select **Output | Display** land cover maps, and click the yellow button (**Animate**) to see the spatial and temporal land cover dynamic.



- The menu **Output | Display** fire maps is to display the dynamic of fire events.



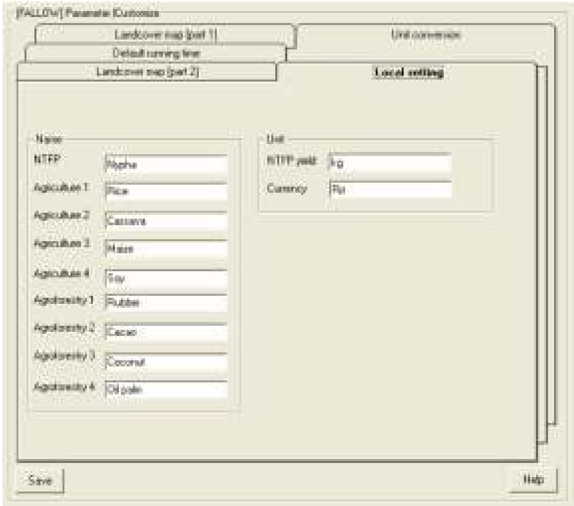
- The menu **Output | Display** carbon maps is to display the dynamic of aboveground carbon reserve.



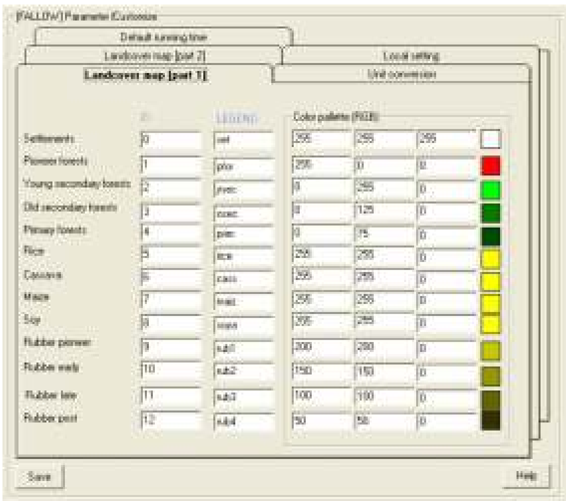
4.5 Modifying non-spatial parameters from default scenario

4.5.1 Customization

- If you have opened a scenario file, you can make modifications of parameter values through the menu **Parameter**.
- The menu option **Parameter | Customize | Local Setting** is used to set the name of land use system, unit of Non Timber Forest Product (NTFP), and local currency. We provide 4 kinds of agricultural systems, 4 types of agroforestry systems (including tree-based monoculture), and 1 harvesting system of NTFP. Note: the unit of agroforestry and agricultural products is ton; the unit of logged timber forest is **m**^{3}.



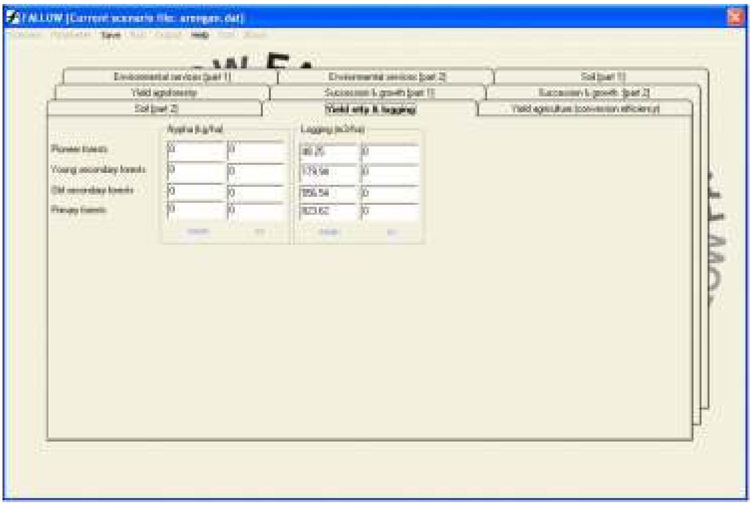
- You can also specify land cover id, label and colour (composed of RGB colour) displayed in the map legend through the menu **Parameter | Customize | Landcover map (part 1)** and **Parameter | Customize | Landcover map (part 2)**.



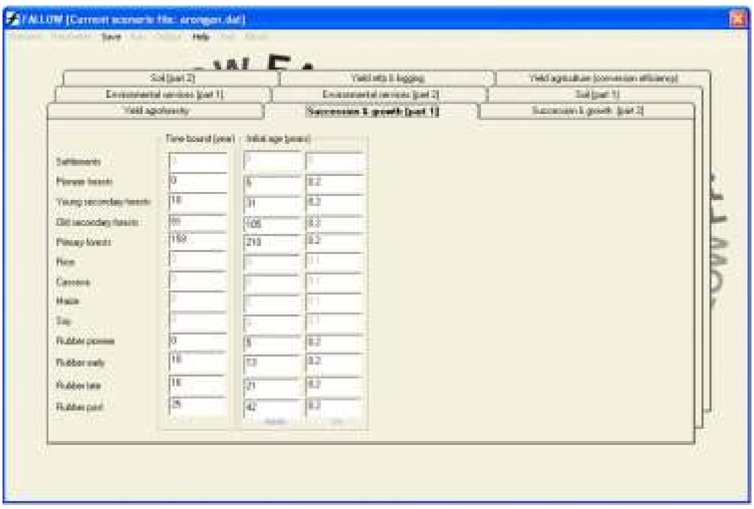
- The menu option **Parameter | Customize | Default running time** is used to specify default simulation time (in year). The menu **Unit conversion** asks you about the conversion unit from biomass to carbon (dimensionless) and from timber volume (m^3) to biomass (ton).
- Click Save button to save and quit the window.

4.5.2 Modifying biophysical parameters

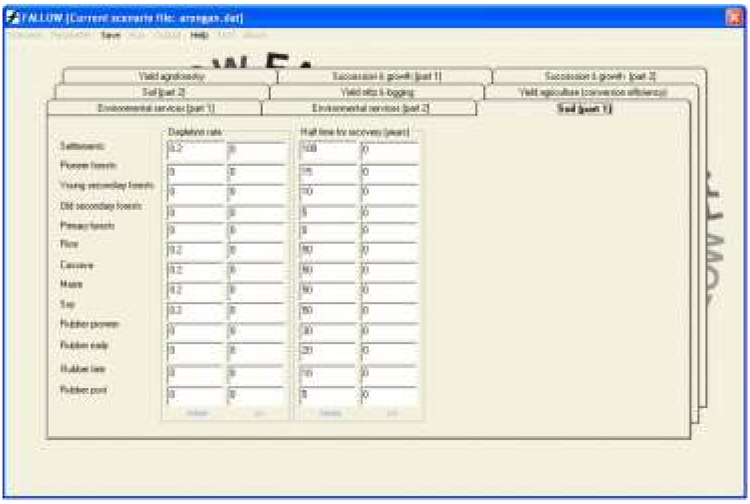
- The menu option **Parameter | Biophysics | Yield ntfp & logging** specifies the mean and coefficient of variation (CV) of NTFP and timber product from each succession stage of forest cover (pioneer, young secondary, old secondary and primary forest). Yield from timber forest is measured in m^3 ha^{-1} whereas for NTFP is according to the unit specified in the menu **Local setting** (part 4.5.1).



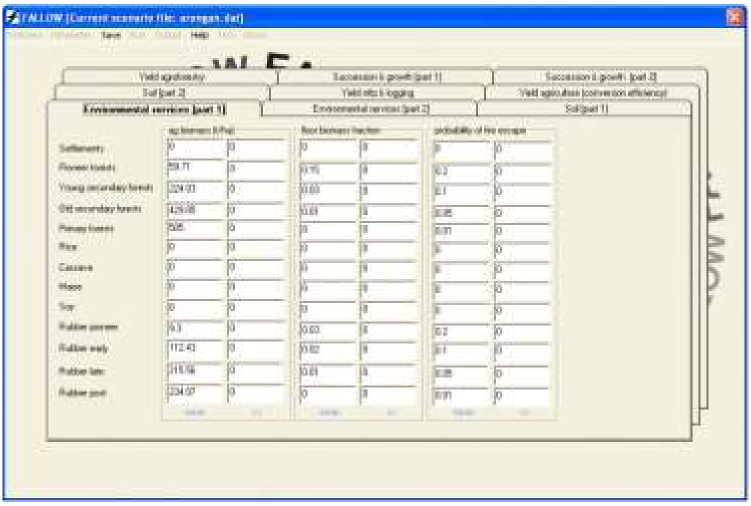
- The menu **Parameter | Biophysics | Yield** agriculture (conversion efficiency) is to specify the statistics (mean and CV) of agricultural crop efficiency to convert soil fertility used by the crop into attainable crop yield. The menu Parameter|Biophysics|Yield agroforestry is to specify the statistics (mean and CV) of agroforestry yield. Agricultural yield and agroforestry products (assumed to be non-timber) are measured in ton ha^{-1}.
- You can determine the minimum land cover age (time bound, year) of each succession or productivity stage in the menu **Parameter | Biophysics | Succession & growth (part 1 and 2)**. The mean and CV value of each land cover type used to generate initialize plot ages are also to be set here. See Appendix 6 for more explanations.



- Soil depletion rate is measured qualitatively, and the period needed to achieve half of maximum soil fertility level is **Half time for recovery** (years) contained in the menu **Parameter|Biophysics|Soil (part 1 and 2)**. Please see Appendix 7 for more explanations.



- The menu option **Parameter | Biophysics | Environmental** services (**part 1 dan 2**) is used to parameterize indicators of environmental service, i.e. aboveground biomass (ton ha^{-1}), floor biomass fraction, and the probability of fire spread from adjacent plots. Please see Appendix 3 and 5 for a more detailed explanation.

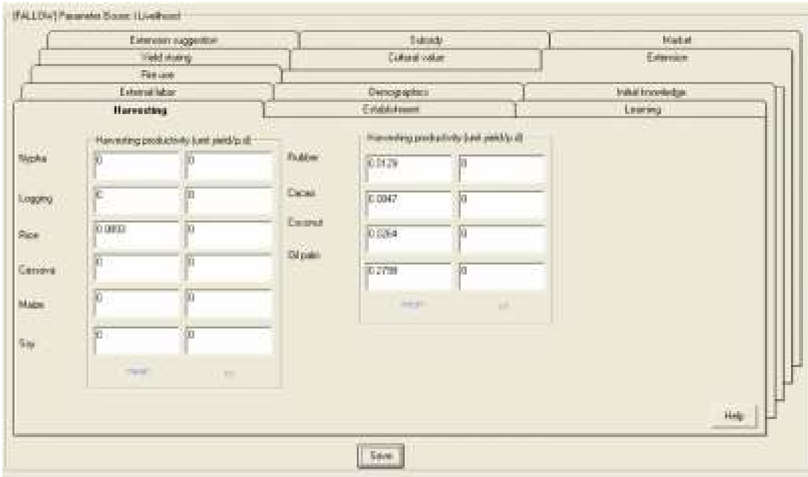


- Please click the option **Save** to save and quit the window.

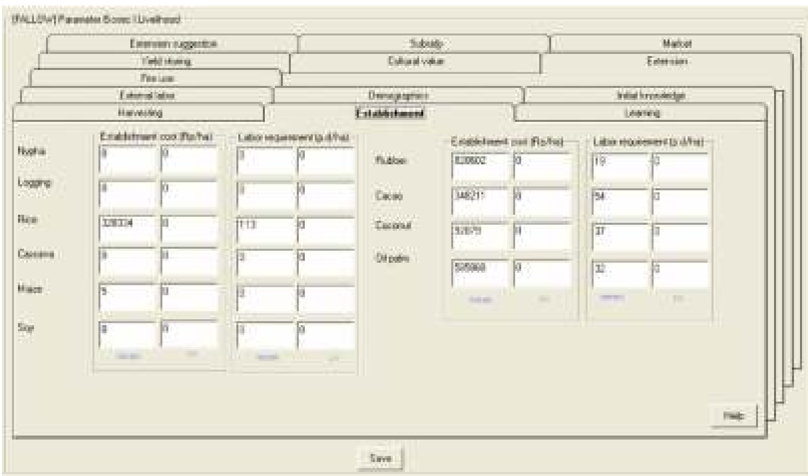
4.5.3 Modifying socio-economic parameters

<u>4.5.3.1 Livelihood</u>

- The menu **Parameter | Sosec | Livelihood** contains 13 parts. **Harvesting** is to parameterize labour harvesting productivity (unit yield person $days^{-1}$). See Appendix 9 for more explanations.

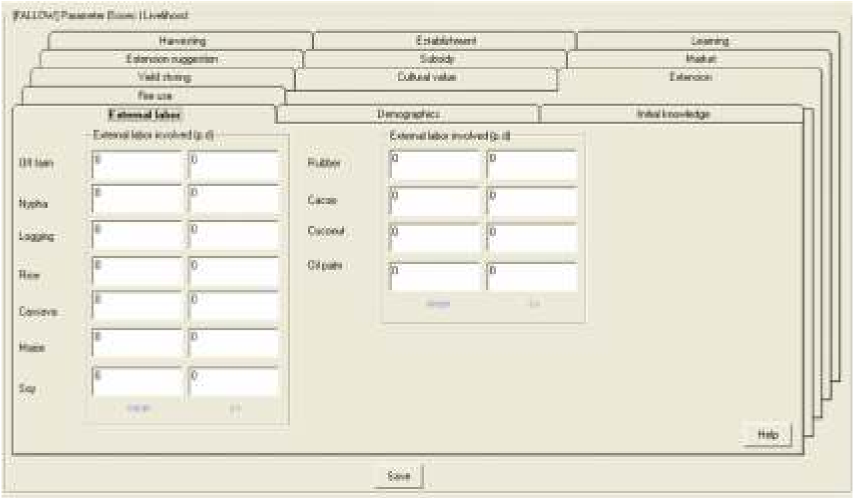


- **Establishment** specifies establishment cost (Rp ha^{-1}) and labour (person day ha^{-1}) required to open a new plot. See Appendix 3 for more explanations.

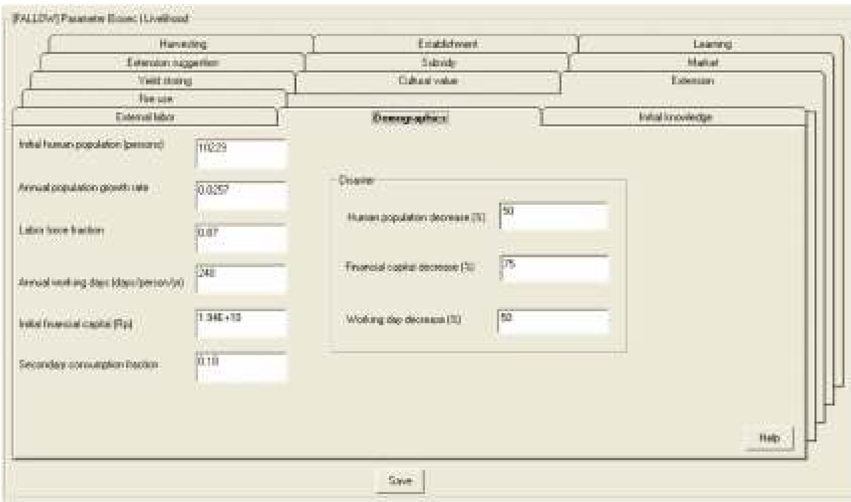


- **Learning** provides cognitive parameters of two types of farmers as explained before. Please see Appendix 1 and 2 for a more detailed explanation.

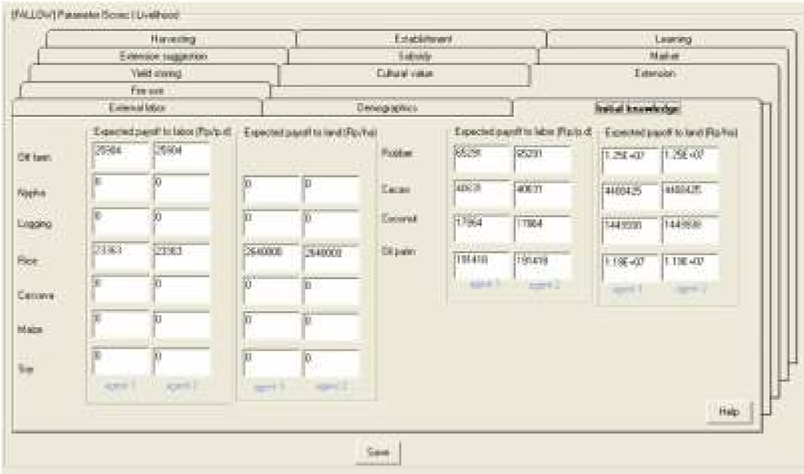
- **External labour** describes total labours involved (person day).



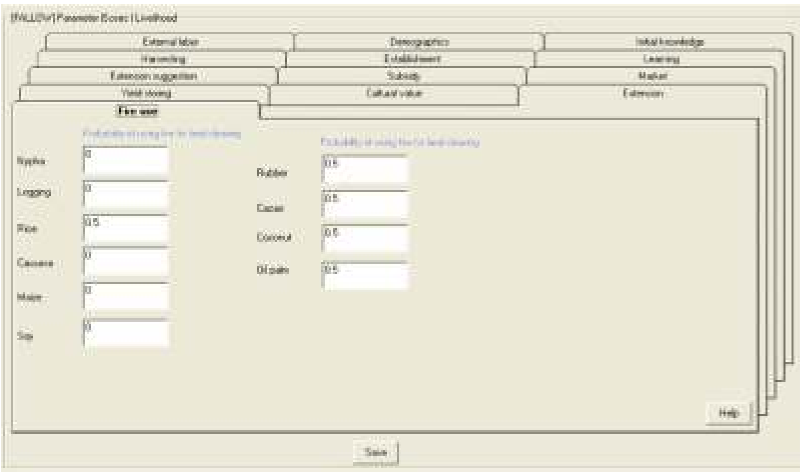
- **Demographics** is to specify initial population (person), annual population growth rate, labour fraction in the population, annual person days, initial financial capital, and secondary consumption fraction from net income. In case of disaster (e.g. tsunami), decline rate (%) of human population, financial capital, and annual person day are also to determine. Please see Appendix 2 for more explanations.



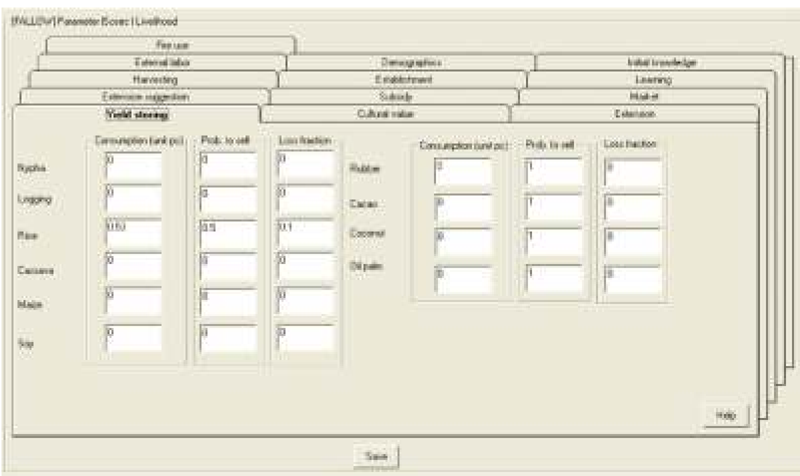
- **Initial Knowledge** is used to parameterize initial expectation of gain per labour (Rp person day-1) and per land resource (Rp ha^{-1}) from each livelihood option based the perception of two cognitive groups. Please see Appendix 1 and 2 for explanation.



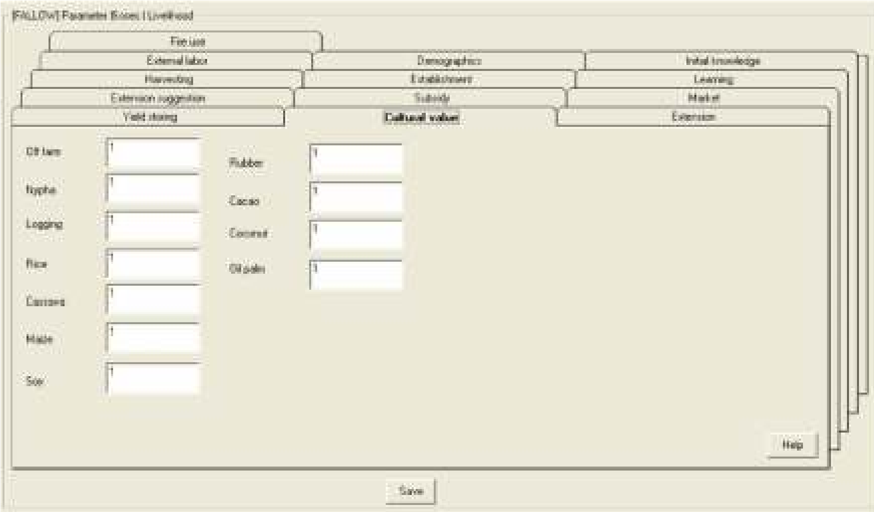
- **Fire use** describes the possibility to use fire for land clearing, for each livelihood option. Please see Appendix 5 for explanation.



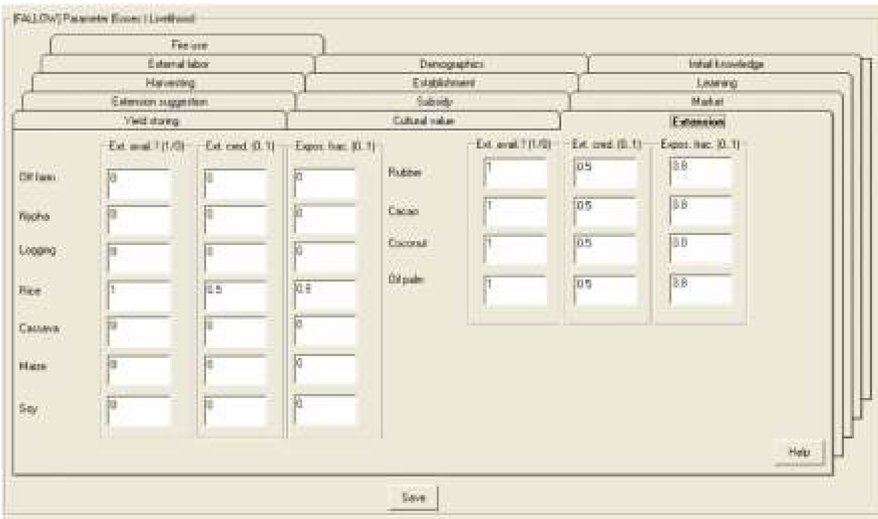
- **Yield storing** is used to parameterize domestic consumption rate per capita (unit per capita), the probability to sell surplus yield (after domestic consumption is fulfilled) and loss fraction from storehouse for all commodities. Please see Appendix 9 for explanation.



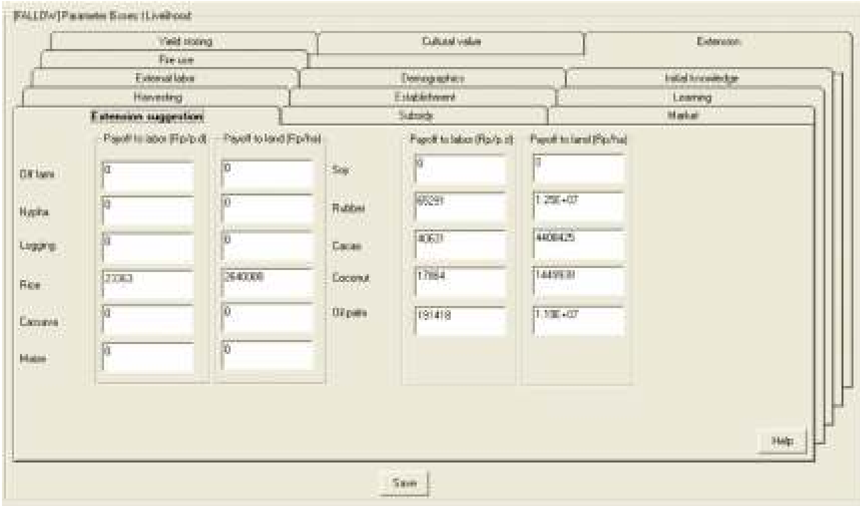
- **Cultural value** describes weighting factors for gains obtained from livelihood options. These factors represent consideration besides economical value (e.g. related to cultural consideration) performed by farmers to take decision related to future livelihood options. Please see Appendix 2 for more explanations.



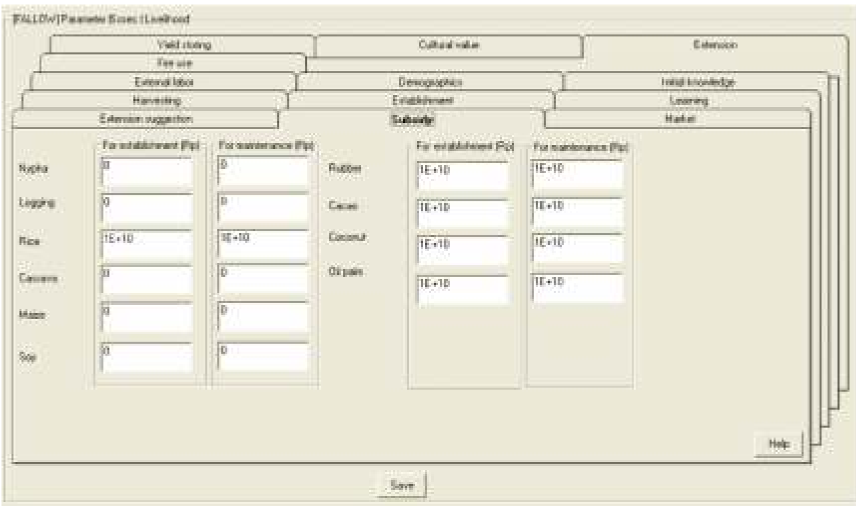
- **Extension** is to specify extension availability, extension credibility (based on farmer perception), and farmer exposure to extension. Please see Appendix 1 for explanation.



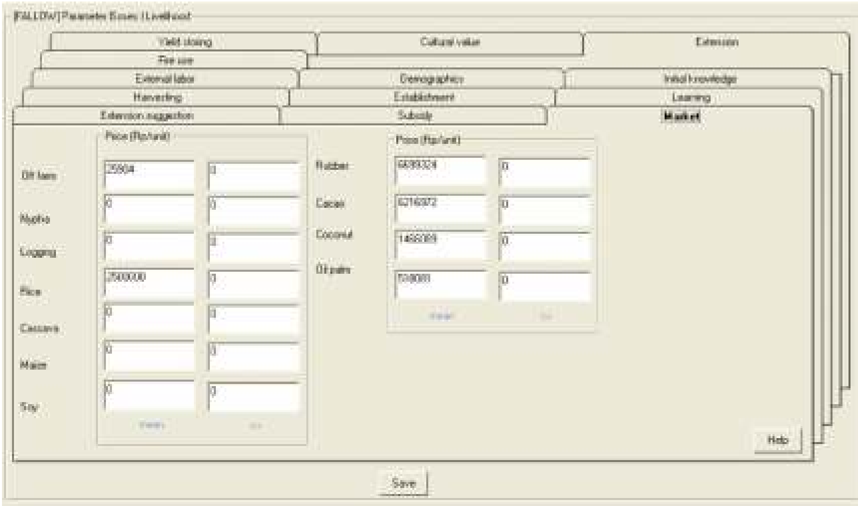
- **Suggestion** describes suggestions from extension agencies related to expected gain from each livelihood option, per labour (Rp person days^{-1}) or land resource (Rp ha^{-1}). Please see Appendix 1 for more explanations.



- **Subsidy** provides the amount of subsidy for land clearing and maintenance (Rp). Please see Appendix 2 for explanation.



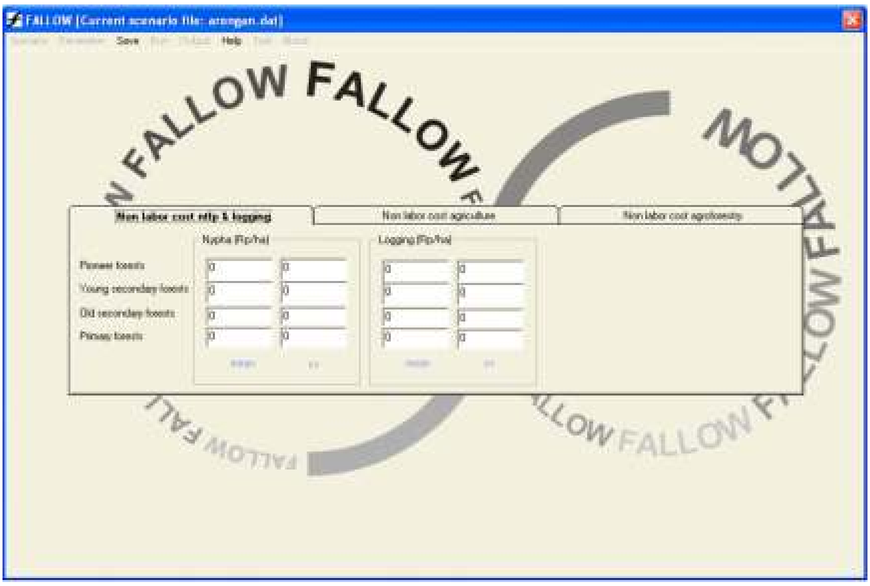
- **Market** describes price of each commodity type from land-based livelihood options (Rp unit commodity^{-1}) and salary per person day of off-farm jobs. Please see Appendix 1 for more explanations.



- Please select the menu **Save** to save and quit the window.

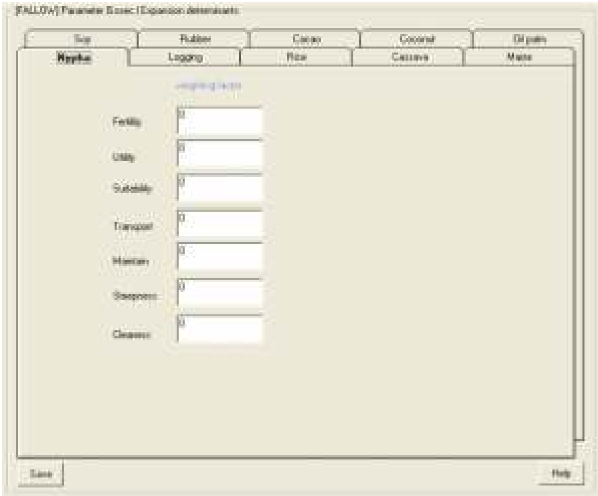
4.5.3.2 Non-labour cost

- **Parameter | Sosec | Non-labour cost** describes total non-labour cost required to establish and maintain NTFP, logging, agricultural, and agroforestry systems, at each succession and production stage (Rp ha^{-1}). Please see Appendix 1 for more explanations.



4.5.3.3 Land expansion determinants

- The menu option **Parameter | Sosec | Expansion determinants** is used to give value for the weighting factor of all aspects considered in land expansion. Please see Appendix 1.4 for explanation.



- Please click the menu **Save** to save and quit the window.

4.5.3.4 Time Series Data

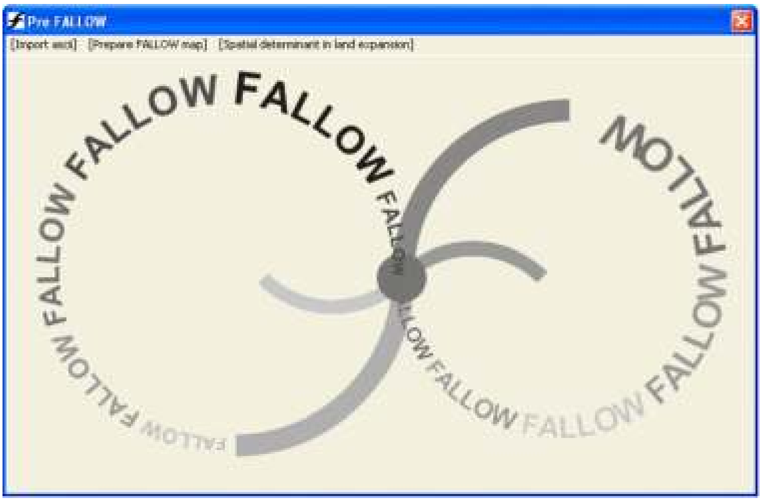
- The values of exogenous factors such as price (Rp yield^{-1} for land-based livelihood options or Rp person day-1 for other options), availability of extension, and availability of subsidy can be introduced to the model in the form of time series or generated based on statistical values. In this menu option **Parameter | Sosec | Time series**, if the choice to use time series data is unchecked (off) then price will be generated based on statistical values specified in the menu **Parameter | Sosec | Market**. Availability of extension and subsidy will be constant according to the values given in the menu **Parameter | Sosec | Extension** and **Parameter | Sosec | Subsidy respectively**.

- Please click the button Save to save and quit the window.

4.6 Modifying maps

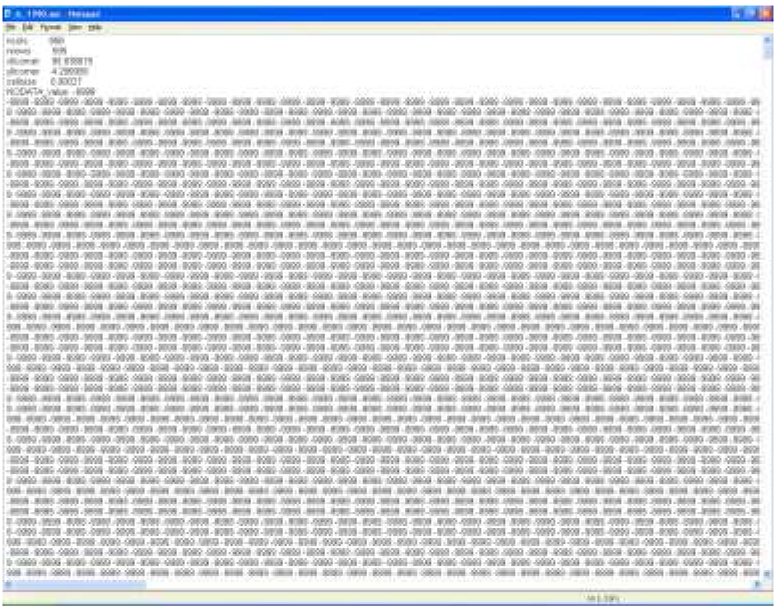
4.6.1 Preparing maps

- Please select the menu **Tool | Pre FALLOW**, and the following window will appear.



4.6.2 Converting ASCII grid file

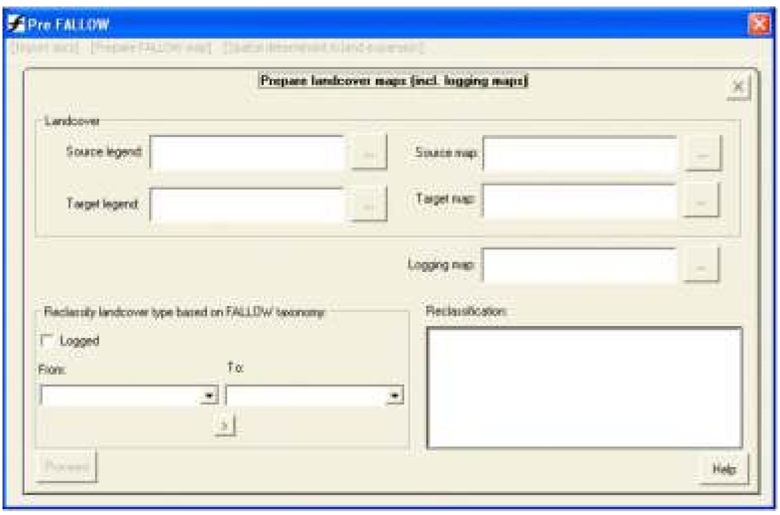
- The menu option **[Import ASCII]** is used to convert ASCII grid file to PCRaster maps (*.RMP). The maps (*.RMP) cannot, however, be directly used by the FALLOW model. We need a further step in order to prepare maps for FALLOW. In the dialog box, please select the name of ASCII grid file (*.ASC) to be converted, and then please name the PCRaster file (*.RMP) as the result of conversion. Please also specify the type of map that you want to create: scalar or Boolean. The unit is also to determine, meter or minute. Afterwards, please select the button **Convert**.



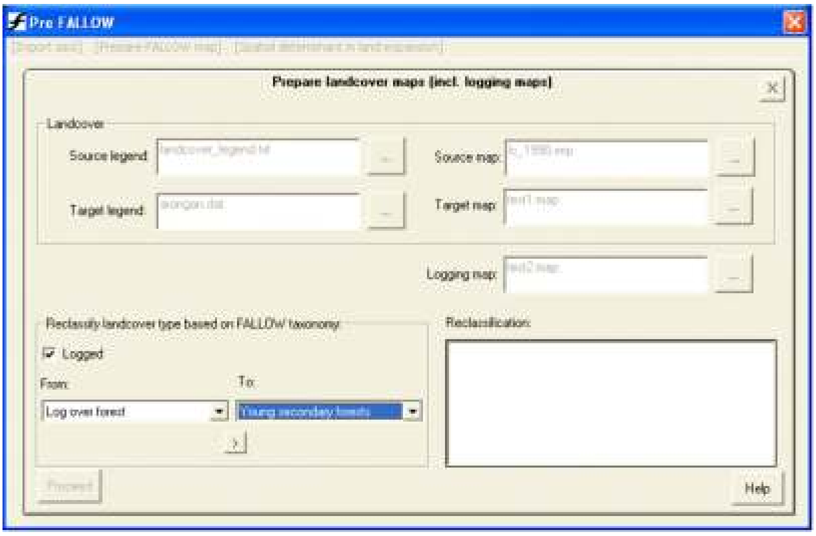
4.6.3 Preparing FALLOW input maps

4.6.3.1 Land cover maps and initial logging

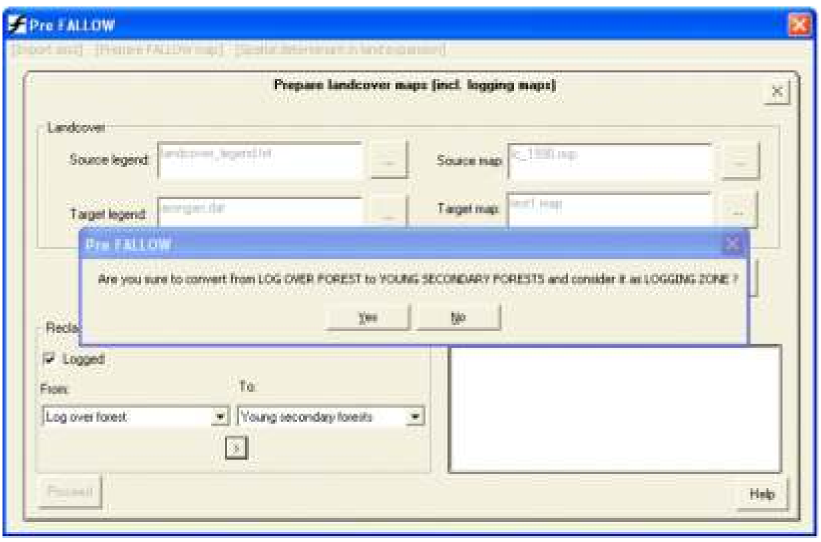
- The menu option **[Prepare FALLOW map] | Landcover** is to prepare FALLOW input maps (*.MAP) for initial land cover and initial logging map. The first is of scalar type. In the FALLOW model, logging zones are considered as land cover areas that reach a certain ecological maturation level or succession stage (please see Appendix 6). Nevertheless, to identify land cover areas that had been logged, we need a Boolean map that delineates the logging zones. As data source, we need land cover map in PCRaster format (*.RMP), and legend file (*.DBF) that has been converted into file with tab delimited (*.TXT) mode. The latter contains information of initial maps legend. This procedure will also ask you to reclassify land cover classes from initial classification to FALLOW classification according to the legend and id information for each land cover class specified through the menu option **Parameter | Customize | Landcover (part 1 & 2) (see part 4.5.1)**. Therefore, we also need to specify file legend from current scenario file (*.DAT). Afterwards, you have to identify the name of the target file (*.MAP) for land cover map and initial logging zone.



- After you specify the name of input and target files, you can use the two drop down lists and a check box to perform the reclassification. The left drop down list contains source map legend; the right one will contain FALLOW map legend. The check box is used to determine whether the land cover class is to be classified as logging zone or not. For example, **Cloud** in the source map legend will be reclassified as **No Data** in FALLOW map, and it is surely not a logging zone so we should not click the check box. Another example, **Logged over forest** will be reclassified as **Young secondary forest** and can be considered as logging zone, so please click the check box.



- After you reclassify the land cover types and determine if they will be classified as logging zones or not, please click the button **>**. Please confirm for a correct reclassification by clicking the button **Yes**.

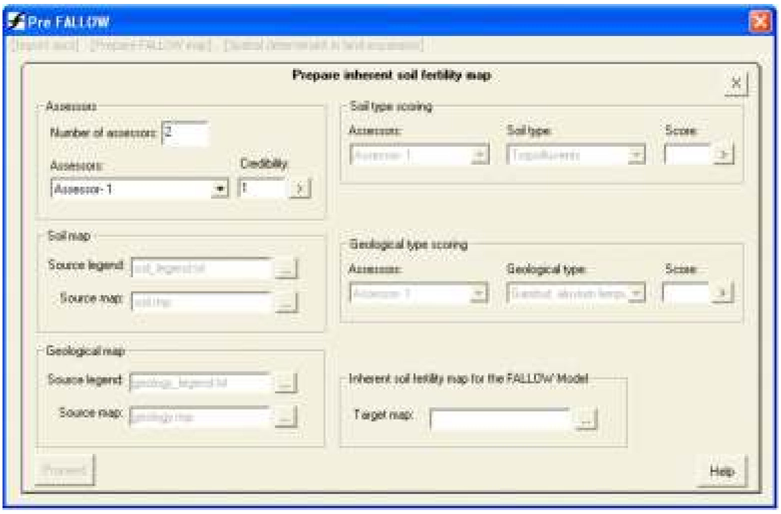


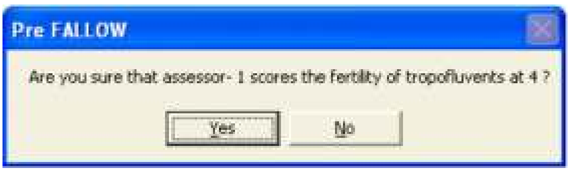
- After all land cover classes in the source map have been reclassified, please click the button **Proceed**. Please wait until the resulted map appears.

- The map produced by this procedure will be used as input in the menu option **Parameter | Map | Static** or **initial map | Initial maps**.

4.6.3.2 Inherent soil fertility map

- The menu option **[Prepare FALLOW map]|Inherent soil fertility** is used to prepare FALLOW input map (*.MAP) for inherent soil fertility. Inherent soil fertility is of scalar type. As data source, we need PCRaster maps of soil type and geological classes and also legend files (*.DBF) that have been converted into files with tab delimited (*.TXT) format. This procedure will produce soil fertility classes according to opinion from soil experts (soil scientist or farmer) based on map of soil or geological classes. You should ask at least two experts, and weight the credibility of each expert. From each of available soil and geological classes, you should ask the experts to give a score of qualitative soil fertility (for example, 0 = very unfertile to 5 = very fertile).





- After you do the scoring for all classes, both for soil and geological class maps, please name the produced inherent soil fertility map (*.MAP). Please give a name that is specific and easily identified. Please click the button **Proceed** until the produced map appears.
- The resulted map will be used as input in the menu option **Parameter | Map | Static or initial map | Other maps**.

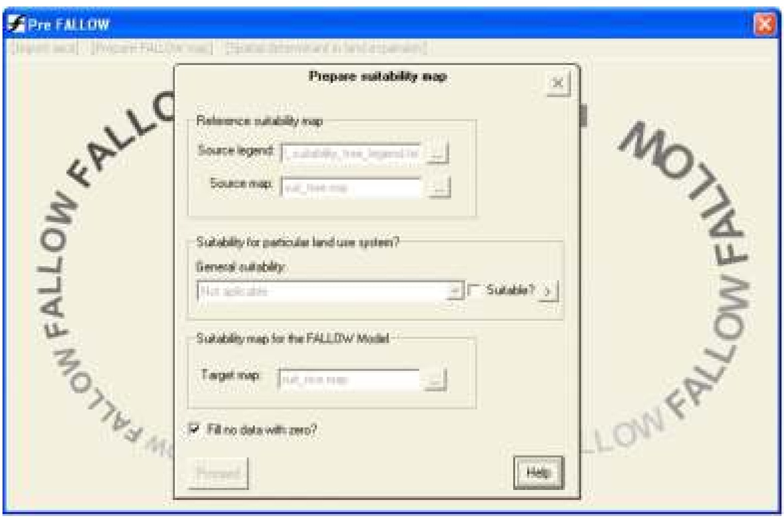
4.6.3.3 Initial actual soil fertility map

- The menu option **[Prepare FALLOW map] | Actual soil fertility** is used to prepare FALLOW input maps (*.MAP) for initial actual soil fertility. It is of scalar type. As data source, we need FALLOW maps (*.MAP) of inherent soil fertility (see part 4.6.1.3.2), initial land cover map (see part 4.6.1.3.1), and also scenario file (*.DAT) that contains the legend of land cover maps. This procedure will estimate initial actual soil fertility based on the two maps, with an assumption that the initial actual soil fertility is lower than or equals the inherent soil fertility depending on land cover type. Therefore, you will be asked to determine the mean and CV of actual soil fertility fraction relative to inherent soil fertility.

- Please name the produced initial actual soil fertility map (*.MAP). Please give a name that is specific and easily-identified. Please click the button **Proceed** until a map appears.
- The resulted map will be used as input in the menu option **Parameter | Map | Static or initial map | Initial maps**.

4.6.3.4 Land Suitability Map

- The menu option **[Prepare FALLOW map] | Suitability** is used to prepare FALLOW input maps describing suitability of certain land use system. It is of scalar type. As data source, we need PCRaster map of land suitability and its legend file (*.DBF) that has been converted into tab delimited format (*.TXT). What you should do in this procedure is to evaluate whether the land suitability classes from original map match with landuse types. It is most likely that the survey carried out for land suitability mapping does not cover all studied areas, so the option to set the un-surveyed areas with 0 (not suitable) becomes default option. If the check box is not selected then the un-surveyed areas are considered as areas without data and this will reduce the areas simulated by the FALLOW model.



- The resulted map will be used as input in the menu option **Parameter |Map | Static or initial map | Suitability map**.

4.6.3.5 Distance map

- The menu **[Prepare FALLOW map] | Distance** is used to prepare FALLOW input map (*.MAP) describing distance to infrastructure (road, market, settlement, and factory). It is of scalar type. As data source, we need PCRaster distance map. If it is not relevant to provide a certain distance map in the studied area, for example distance to cacao factory and in the studied landscape or around, there is no cacao factory at all, then you are only necessary to insert an arbitrary file (*.RMP) of distance map and select the check box: no available objects to measure distance? In this condition, the distance map will be a uniform map with values of 1010, which means a very long distance.

- The resulted map will be used as input in **Parameter | Map | Dynamic** map.

4.6.3.6 Slope map

- The menu option **[Prepare FALLOW map] | Slope** is used to prepare slope map with scalar type. As data source, we need an elevation map in PCRaster format (m above sea level). This procedure will convert elevation map into slope map (degree).

- The resulted map will serve as input in the menu option **Parameter | Map | Static or initial map | Other maps**.

4.6.3.7 Reserved area map

- The menu option **[Prepare FALLOW map] | Forest reserve** is to prepare reserved area map. It is of Boolean type. As data source, we need reserved area map of scalar type with a zero value for areas outside reserved areas and a unit value for areas inside reserved areas. If no reserved areas are simulated in the model, the check box option: **No forest reserve?** is available, with any scalar map (*.MAP) as an input.

- The resulted map will be used in the menu option Parameter|Map|Static or initial map|Other maps.
- This procedure can also be used to create area maps with disaster impact (like tsunami) that will be used as input in the menu option **Parameter | Map | Disaster map**.

4.6.3.8 Working area map for FALLOW model

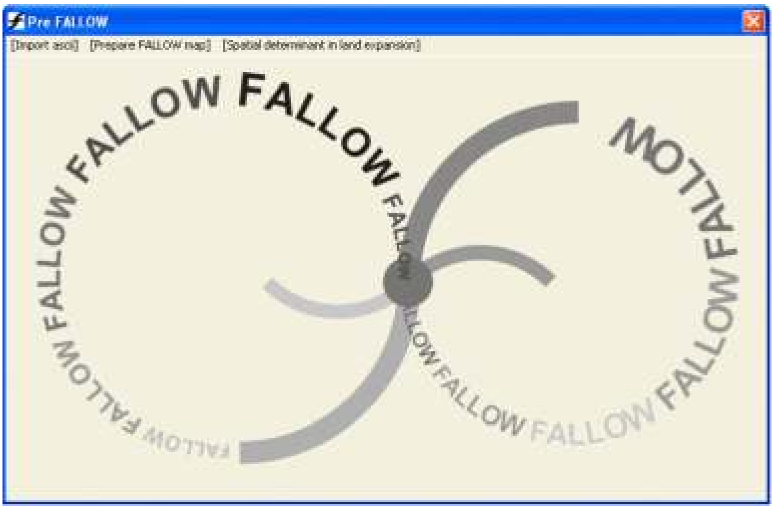
- The menu option **[Prepare FALLOW map] | Working area** is used to prepare working area map, i.e. map of scalar type with unit values. This map is absolutely necessary for all PCRaster models. A check box option is available: **Fill no data?** To fill the working area map with unit values (without **no data** information).

- The resulted map from this procedure will be used as input in **Parameter | Map | Static or initial map|Other maps**.

4.7 Spatial analysis to estimate parameters related to land expansion determinant

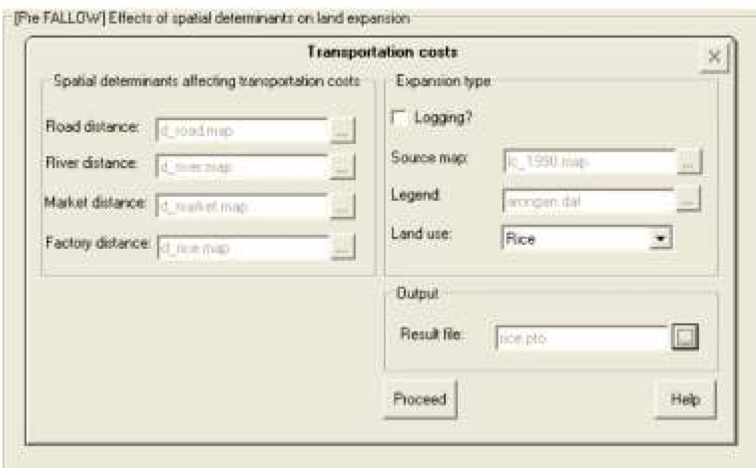
In FALLOW model, farmers will consider plot attractiveness related to potential transportation cost to determine if a plot is attractive or not to be cleared into new plot with certain landuse type (see also part 4.5.3.3. and Appendix 4.). One of possible methods to measure the consideration is through survey, asking farmer perception of each factor that determines land expansion as listed in the Equation 6 of Appendix 1.4. Another way is to observe conversion of empirical lands from available land cover maps, associated with the maps of land expansion determinant (distance to road, distance to market, etc). The following procedure is to perform a spatial analysis as an alternative in measuring the consideration.

- Please select the menu option **Tool | Pre FALLOW**

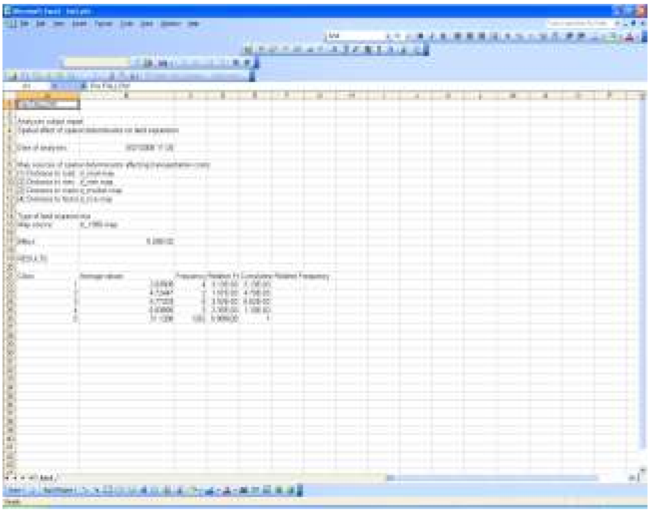


4.7.1. Determinant of land spatial expansion related to transportation cost

- The menu option **[Spatial determinant in land expansion] | Transportation cost** is to measure consideration related to transportation cost. As data source, we need FALLOW map of distance to road, distance to river, distance to market, distance to factory of related commodity, and land cover. These are scalar maps. Other data source required is land cover legend contained in the related scenario file (*.DAT). If the analysis is carried out for expansion of logging areas, after checking the check box option **Logging?** scalar land cover map is replaced by Boolean land cover map.



- Name the resulted file (***.PFO**). The result of analysis can be seen in **MS Excel** as **text file** in **tab delimited** format.



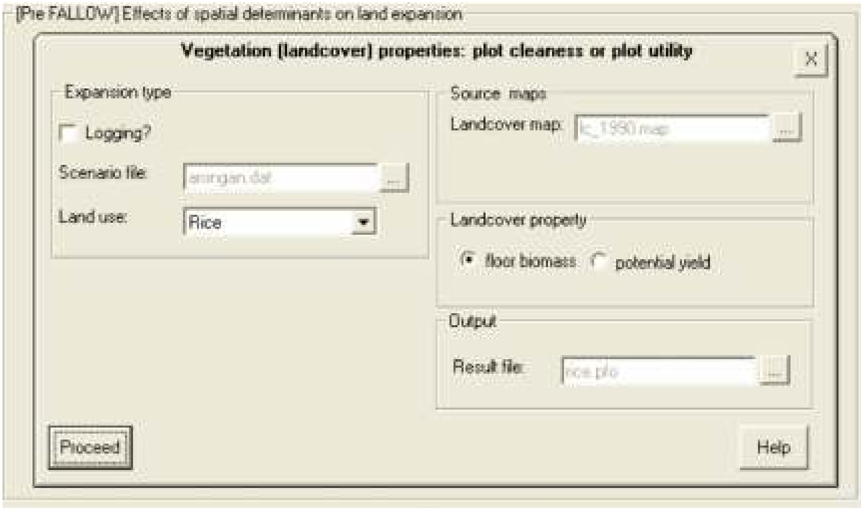
4.7.2 Spatial land expansion determinant related to maintenance

- The menu option **[Spatial determinant in land expansion] | Maintenance cost** is used to measure consideration related to maintenance cost. As data source, we need two FALLOW land cover maps (*.MAP) from two observation periods (for example, land cover map 1990 and 1991). These maps are of scalar type. Another required data source is land cover legend contained in the related scenario file (*.DAT). If analysis is done for expansion of logging areas, scalar land cover map is replaced by Boolean land cover type after checking the check box: **Logging?**

- Name the resulted file (***.PFO**). The result of analysis can be seen in **MS Excel** as **text file** in **tab delimited** format.

4.7.3. Determinant of spatial land expansion related to the benefits and cost determined by vegetation type

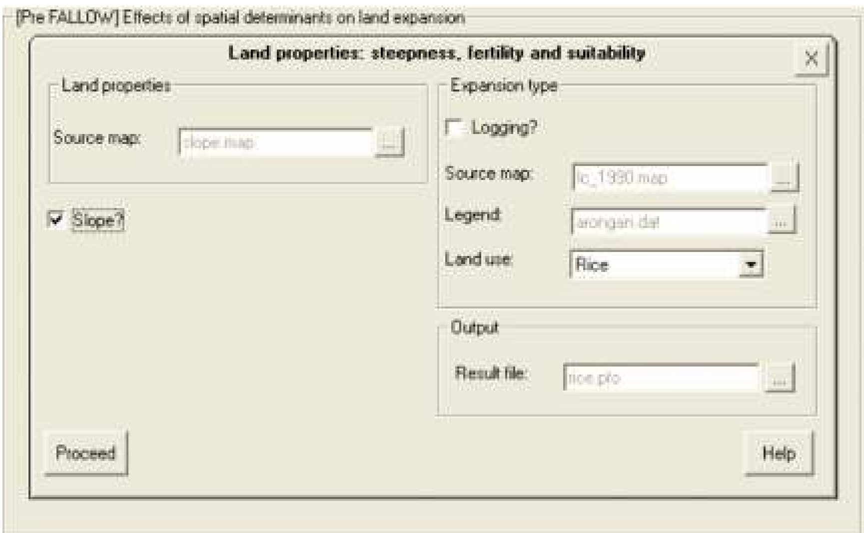
- The menu option **[Spatial determinant in land expansion] | Vegetation properties** is used to measure consideration related to the benefit and cost determined by vegetation type. The benefit is harvested yield (option potential yield) whereas the cost is floor biomass (option floor biomass) that affects land clearing. As data source, we need land cover map of scalar type. Another data source would be land cover legend and other vegetation properties related to floor biomass and potential harvest, contained in the related scenario file (*.DAT). If the analysis is carried out for expansion of logging areas, the scalar land cover map is replaced by Boolean type, after checking the check box option: **Logging?**



- Name the resulted file (***.PFO**). The result of analysis can be seen in **MS Excel** as **text file** in **tab delimited** format.

4.7.4 Determinant of spatial land expansion related to the benefits and cost determined by land type

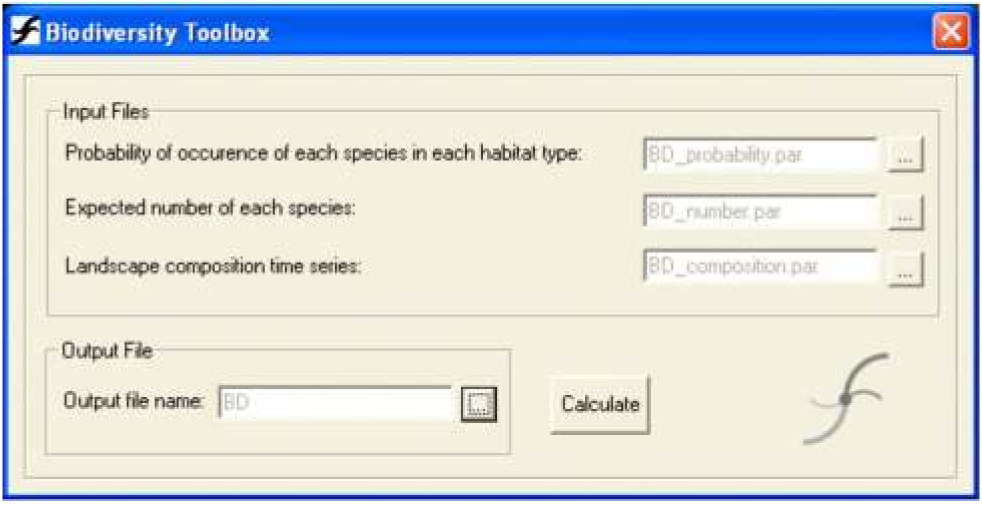
- The menu option **[Spatial determinant in land expansion] | Land properties** is used to measure consideration related to the benefit and cost determined by land type. The benefit is land fertility and suitability. If the aspect being analysed is slope, the check box option: **Slope?** Should be selected. Slope is assumed to be proportional to the cost. If the analysis is carried out for expansion of logging areas, the scalar land cover map is replaced by Boolean type, after checking the check box option **Logging?**



- Name the resulted file (*.PFO). The result of analysis can be seen in **MS Excel** as **text file** in **tab delimited** format.

4.8 Estimate the impact of land cover change to biodiversity

- The **toolbox** to measure the impact of land cover change to biodiversity is made separately after landuse change simulation (see Appendix 10 for more explanations).
- Please select the menu option **Tool | Post FALLOW | Biodiversity toolbox**

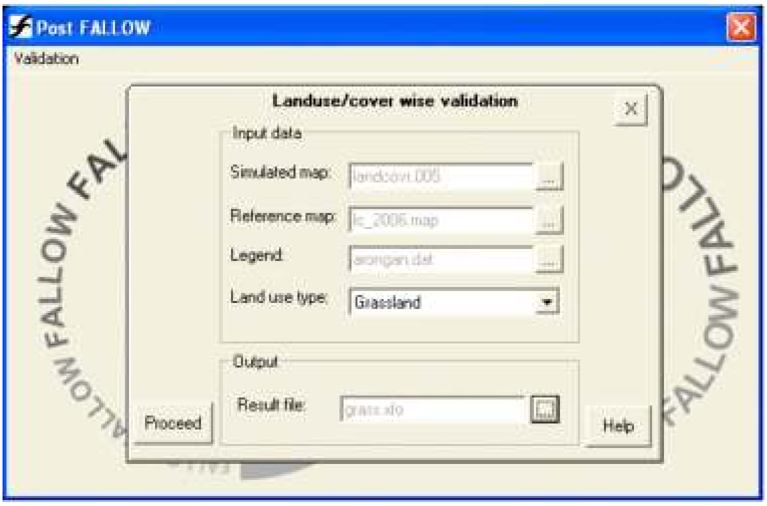


- We need 3 input files (*.PAR). These are text files in the tab delimited mode with a specific format. The first describes the probability that a certain species is found in certain habitat type. Please see **BD_probability.par** as an example. Please open this file with MS Excel in tab delimited mode. The first column refers to a habitat type with the first line as a header. Other column refers to the probability that a certain species is found in a certain habitat type where the first line refers to the name of the species or the observed species group. The name and order of the habitat and species (or species group) in this file should be the same with other related input data files. You are allowed to determine the number of habitat and species according to your need, as long as it is done consistently to each related input data file.
- The second file describes the expected maximum number of species member or species group. Please see **BD_number.par** for example. Please open with MS Excel in the **tab** delimited text mode. The first column refers to species type (or group of species) with the first line as header. The second column refers to the expected maximum numbers of species member or species group, where the first line as header. The name and order of the habitat and species (or species group) in this file should be the same with other related input data files. You are allowed to determine the number of species and species group according to your need, as long as it is done consistently to each related input data file.
- The third file describes the dynamic of landscape composition in the observed areas. Please see **BD_composition.par** as an example and open this file with MS Excel in the tab delimited text mode. The first column refers to habitat type (land cover) with the first line as a header. Other column refers to area data (ha) from each habitat type, describing the dynamic of landscape composition where the first line refers to the label of landscape composition dynamic: whether it is based on time series, case or scenario. The name and order of the habitat and species (or species group) in this file should be the same with other related input data files. You are allowed to determine habitat type according to your need, as long as it is done consistently to each related input data file. The data for this file can take FALLOW simulation result as the source.

- If the above input files are not compatible in size and contain different habitat names or species (species groups), the program will give a warning to perform checking input data file.
- Name the output file (can be ignored and the program will give a default name: **default.out**). Please click the button **Calculate**.
- The output file is text file in the tab delimited mode and can be seen with MS Excel.

4.9. Validate the result of land cover simulation

- Please select the menu option Tool|Post FALLOW|Validation. As data source is the results of land cover simulation (*.#*), referred land cover map (*.MAP), and land cover legend contained in the related scenario file (*.DAT).



- Name the resulted output file (*.XFO). The result of the analysis can be seen with MS Excel as text file in tab delimited mode.

4.10. Learning some concepts of FALLOW model

Please select the menu option **Tool | Learn FALLOW**. This tool can be used to learn FALLOW concept on succession and growth (Appendix 6), land expansion (Appendix 3-4), cognitive process (Appendix 1), and resource allocation (Appendix 2).

References

Chomitz, K.M., 2007. At loggerheads? Agricultural expansion, poverty reduction and environment in the tropical forests. World Bank Policy Research Report, the Worldbank, Washington (DC), USA.

Suyamto, D.A., van Noordwijk, M., Lusiana, B., Ekadinata, A. and Khasanah, N., 2005. Prospects of adoption of tree-based systems in a rural landscape and its likely impacts on carbon stocks and farmers welfare: the FALLOW model application in Muara Sungkai, Lampung, Sumatra, in a "Clean Development Mechanism" context. ICRAF Southeast Asia Working Paper No. 2005_4.

Tomich, T.P., Van Noordwijk, M., Budidarseno, S., Gillison, A., Kusumanto T., Murdiyarso, D. Stolle, F. and Fagi, A.M., 2001 Agricultural intensification, deforestation, and the environment: assessing tradeoffs in Sumatra, Indonesia. In: Lee D.R. and Barrett, C.B. (eds.) Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment. CAB-International, Wallingford pp 221-244

Van Noordwijk, M. 1996. Model as part of agroforestry research design. IC-SEA Training course on Ecosystem Modelling Tools for the Analysis of Impacts of Global Change on Sustainable Management of Tropical Forests. IC-SEA/Biotrop, Bogor.

Van Noordwijk, M., 1999 Productivity of intensified crop fallow rotations in the Trenbath model. Agroforestry Systems 47: 223-237

Van Noordwijk, M., 2002. Scaling trade-offs between crop productivity, carbon stocks and biodiversity in shifting cultivation landscape mosaics: the FALLOW model. Ecol. Model. 149, 113126.

Van Noordwijk, M., Suyamto, D.A., Lusiana, B., Ekadinata, A. and Hairiah, K., 2008. Facilitating agroforestation of landscapes for sustainable benefits: tradeoffs between carbon stocks and local development benefits in Indonesia according to the FALLOW model. Agriculture Ecosystems and Environment 126: 98-112. Doi:10.1016/j.agee.2008.01.016

Suggested readings:

Suyamto, D., van Noordwijk, M. Hadi D.P. and Lusiana, B., 2003. FALLOW model: assessment tool for landscape level impact of farmer land use choice. In: Post, D.A. (Ed.): Proceedings of International Congress on Modelling and Simulation of Modelling and Simulation Society of Australia and New Zealand Inc. on Integrative Modelling of Biophysical, Social and Economic Systems for Resource Management Solutions (MODSIM 2003), Jupiter Hotel and Casino, Townsville, Australia, 14-17 July 2003.

Suyamto, D.A. and van Noordwijk, M., 2005. Scenario studies of land use in Nunukan, East Kalimantan (Indonesia): drivers, local livelihoods and globally relevant carbon stocks. In: Lusiana, B., van Noordwijk, M. and Rahayu, S. (Eds.),Carbon stock monitoring in Nunukan, East Kalimantan: a spatial modelling approach. World Agroforestry Centre, Bogor (Indonesia). Pp 55-77

Suyamto, D.A., Van Noordwijk, M., Lusiana, B.. 2006. Way Tenong and Sidrap: Tree Planting and Poverty Alleviation, Indonesia. In: Murdiyarso, D. and Skutsch (Eds.): Community Forest Management as a Carbon Mitigation Option: Case Studies. Center for International Forestry Research (CIFOR), Bogor, Indonesia. ISBN: 979-24-4660-5. pp: 74-84.

Van Noordwijk, M., 2001. Understanding local action and its consequences for global concerns in a forest margin landscape: the FALLOW model as a conceptual model of transitions from shifting cultivation. ASB_LN 11B. In: Van Noordwijk, M, Williams, S.E. and Verbist, B. (Eds.) 2001.Towards integrated natural resource management in forest margins of the humid tropics: local action and global concerns. ASB-Lecture Notes 1 12. International Centre for Research in Agroforestry (ICRAF), Bogor, Indonesia. Also available from:
http://www.icraf.cgiar.org/sea/Training/Materials/ASB-TM/ASB-ICRAFSEA-LN.htm

Appendix 1

How do farmers adjust their expectation related to the profit from available livelihood options through learning process?

The profit obtained from a certain livelihood option is described as profit per labour Pl (Rp person day^{-1}) and profit per land area Pa (Rp ha^{-1}):

$$P_l = \frac{y.p - c}{C_l} \qquad (1a)$$

$$P_a = \frac{y.p - c}{C_a} \qquad (1b)$$

Where:

P_l and P_a = profit per unit labour or land, respectively (Rp person day^{-1} or Rp ha^{-1}, respectively)
y = total harvest (unit harvest)
p = price of commodity (Rp unit commodity^{-1})
c = total expense (Rp)
C_l and C_a = total investment of labour and land, respectively (person day for labour and ha for land)

The farmer's expectation of the profit that will be obtained from a certain livelihood option will be adjusted according to their own experience at certain rate:

$$E_{t+1} = E_t + \alpha\left(P_t - E_t\right) \qquad (2)$$

Where:

E_{t+1} = next year's expectation (Rp person day^{-1} or Rp ha^{-1})
E_t = current year's expectation (Rp person day^{-1} or Rp ha^{-1})
α = adjustment rate based on current year experience
Pt = current year profit (Rp person day^{-1} or Rp ha^{-1})

When $\alpha = 0$, no adjustment is made for next year. When $\alpha = 1$, farmers will use current year experience as new expectation. Furthermore, farmer expectation to profit can be also influenced by suggestion from others (e.g. extension officer):

$$E_{t+1} = \left[E_t + \alpha\left(P_t - E_t\right)\right] + \left\{\beta\left(S_t - \left[E_t + \alpha\left(P_t - E_t\right)\right]\right)\right\} \qquad (3)$$

Where:

β = adjustment rate related to suggestions from others
S_t = profit suggested by others (Rp person day^{-1} or Rp ha^{-1}).

Farmers can completely abandon ($\beta = 0$) or adopt ($\beta = 1$) suggestions from others.

Appendix 2

How do farmers allocate resource to available livelihood options in their areas?

In allocating available resources (labour, capital, and land) to livelihood options, farmers consider expectation to profit form each option based on a certain prioritization degree:

$$y_i = \frac{(w_i.x_i)^p}{\sum_{i=1}^{N}(w_i.x_i)^p} \quad (4)$$

Where:

y_i = resource fraction allocated to livelihood option i
w_i = weighting factor reflecting non-economical reasons (e.g. cultural value)
x_i = expectation (Rp person day^{-1} or Rp ha^{-1}) calculated from Equation 3
p = prioritization degree

P = 0 suggests that available resources will be allocated uniformly to each livelihood option. P = 1 means resource allocation is proportional to expected profit. Resources are allocated mainly to the most profitable livelihood with $p > 1$.

Labour and capital resource allocation are based on expected profit per labour (Rp person day^{-1}) while land resource allocation is based on expected profit per land area (Rp ha^{-1}).

Total available labour is calculated from total population x labour fraction x annual working days. Initial total capital resource is estimated from total population x annual revenue per capita. Total available capital resource for investment is calculated as a fraction from total budget for secondary consumption and if any, plus subsidy. Total available land resource for land expansion includes total areas of old and marginal plots (e.g. bushes) that can be accessed by farmers.

Appendix 3

How large is the area that can be converted by farmers for land-based livelihood options, based on labour and financial capital?

Total land area that can be converted by farmers for land-based livelihood options option, based on labour and financial capital is calculated as follows:

$$a_i = \min\left(\frac{l_i}{el_i}, \frac{m_i}{em_i}\right) \qquad (5)$$

Where:

a_i = potential land area to be converted into new plot with livelihood option i (ha)
l_i = allocated labour (person day) based on Equation 4
el_i = labour demand for land clearing (person day ha^{-1})
m_i = total allocated budget for investment (Rp) based on Equation 4
em_i = cost for land clearing (Rp ha^{-1})

Appendix 4

What is farmer perception on spatial factors that will determine potential benefit and potential cost from new cleared plots?

Farmers will consider land attractiveness as the ratio between benefit and potential cost:

$$attr_{i,j} = \frac{wfert.fert_{i,j} + wsuit.suit_{i,j} + wyield.yield_{i,j}}{1 + wtrans.dtrans_{i,j} + wmain.dmain_{i,j} + wslope.slope_{i,j} + wfbiom.fbiom_{i,j}} \quad \text{............ (6)}$$

Where:

$attr_{i,j}$ = attractiveness of plot at coordinate (i, j)
wfert = weighting factor reflecting farmer's consideration on plot soil fertility (0-1)
wsuit = consideration on land suitability (0-1)
wyield = consideration on potential yield (0-1)
wtrans = consideration on potential transportation cost (0-1)
wmain = consideration on potential maintenance cost (0-1)
wslope = consideration on land slope (0-1)
wfbiom = consideration on floor biomass (0-1)
$fert_{i,j}$ = plot fertility classified into 5 classes based on normal distribution of fertility values observed in whole landscape area (see also Equation 9)
$suit_{i,j}$ = plot suitability classified into 5 classes based on normal distribution of suitability values observed in whole landscape area (see also Equation 9)
$yield_{i,j}$ = plot potential yield classified into 5 classes based on normal distribution of yield values observed in whole landscape area (see also Equation 9)
$dtrans_{i,j}$ = plot distance from the closest transportation network classified into 5 classes based on normal distribution of distance values observed in whole landscape area (see also Equation 9)
$dmain_{i,j}$ = plot distance to the closest maintenance centre classified into 5 classes based on normal distribution of distance values observed in whole landscape area (see also Equation 9)
$slope_{i,j}$ = plot inclination classified into 5 classes based on normal distribution of inclination values observed in whole landscape area (see also Equation 9)
$fbiom_{i,j}$ = plot floor biomass classified into 5 classes based on normal distribution of floor biomass values observed in whole landscape area (see also Equation 9)

In this case:

$$dtrans_{i,j} = \min\left(droad_{i,j}, driver_{i,j}, dmart_{i,j}, dind_{i,j}\right) \quad \text{.. (7)}$$

Where:

$dtrans_{i,j}$ = plot distance to the closest transportation network
$droad_{i,j}$ = plot distance to the closest road network
$driver_{i,j}$ = plot distance to the closest river network
$dmart_{i,j}$ = plot distance to the closest market
$dind_{i,j}$ = plot distance to the closest factory

$$dmain_{i,j} = \min\left(dset_{i,j}, dexist_{i,j}\right) \quad \text{(8)}$$

Where:

$dmain_{i,j}$ = plot distance to the closest maintenance centre
$dset_{i,j}$ = plot distance to the closest settlement
$dexist_{i,j}$ = plot distance to other plots with similar livelihood option

Next, $attr_{i,j}$ values will be classified into 5 classes based on normal distribution of attr values calculated in entire observed landscape area:

$$z_{i,j} = \frac{attr_{i,j} - \mu}{\delta} \quad \text{(9)}$$

Where:

$z_{i,j}$ = normal value of plot attractiveness
μ = mean of plot attractiveness in the observed landscape
δ = standard deviation of plot attractiveness in the observed landscape

Finally, plot attractiveness is according to the following criteria:

- Score 1 means very unattractive plots, $z < 0$
- Score 2 means less attractive plots, $0 = z < 1$
- Score 3 means quite attractive plots, $1 = z < 2$
- Score 4 means attractive plots, $2 = z < 3$
- Score 5 means very attractive plots, $z \; 3$

Appendix 5

Which plots do farmers really choose for new investment and whether they use fire for land clearing or not?

Plot probability to be converted to a certain land-based livelihood option is as follow:

For $f_i > 0$ then:

$$pconv_i = \frac{\max(0, \min(f_i, a - fc_i))}{f_i}$$

For $f_i = 0$ then:

$$pconv_i = 0$$

.... (10)

Where:

$pconv_i$ = probability that farmer chooses a plot of land attractiveness class i as new plot
f_i = frequency of plots belong to land attractiveness class i
a = total area of potential new plots calculated based on Equation 5
fc_i = cumulative frequency of land attractive class i

If a generated random value (0-1) is lower than pconvi then conversion of plot i will be executed. The use of fire for clearing new plots is determined by the probability of using fire. Susceptibility of surrounding plots to fire depends on land cover type.

Appendix 6

How are the succession and growth process of a certain plot based on ecological mature and productivity level?

Forest is classified into 4 classes based on ecological mature and succession process:

- pioneer
- young secondary
- old secondary
- primary

While other tree-based land systems are classified into 4 classes based on productivity level and growth process:

- pioneer
- early production
- old production
- post production

For initialization, the succession age and productivity of each plot is estimated based on the specified mean and variation between plots. Next, in the dynamic process, as long as a plot is not converted into another landuse type or burned, plot age will increase. To determine whether plot class changes or not, plot age will be compared with the lowest age required to achieve higher class. If a plot was converted into new plot, plot age will be reset to 0. If fire event occurs, it is assumed that the plot will become pioneer type with plot age equals 0. For the case of logged forests, their status based on ecological mature can be degraded into lower classes if the remaining aboveground biomass after logging is relatively the same with the aboveground biomass of the class below it.

Appendix 7

How are the dynamic of soil fertility and agricultural land productivity?

In FALLOW model, soil fertility is represented by qualitative soil fertility. Soil fertility is defined as the ability of soil to support plant growth. Because all agricultural yields are not remaining in the plot, it is assumed that soil fertility is degrading since the planting time. Soil fertility degradation is equivalent to harvested yield. Each type of agricultural plant has its own efficiency in using soil fertility.

$$y = dr.fert.\varepsilon \qquad (11)$$

Where:

dr = rate of soil fertility degradation due to cropping
fert = qualitative soil fertility (qualitative fertility scale)
y = total attainable yield (ton)
ε = conversion efficiency of the crop

In fallow period of agricultural land or tree-based systems, soil fertility can recover due to remaining harvest in the plot:

$$sr = \frac{(fert_{max} - fert)^2}{(1+hr).fert_{max} - fert} \qquad (12)$$

Where:

sr = addition of soil fertility (qualitative fertility scale)
$fert_{max}$ = maximum soil fertility reflecting inherent soil fertility based on geological class (qualitative fertility scale)
fert = soil fertility before recovery (qualitative fertility scale)
hr = half-time recovery, i.e. time needed to achieve fertmax (year)

Appendix 8

How is the dynamic of land productivity in tree-based systems?

Timber or non-timber (e.g rubber latex, resin, honey, etc) productivity from a plot with tree-based system is estimated based on mean and CV value specified for each succession stage or productivity level as explained in Appendix 6.

Appendix 9

How is the harvesting process of each plot, yield storage, and/or yield selling to the market?

In agriculture systems, yield will be totally harvested whereas in tree-based systems total harvest is estimated as follow:

$$Y_k = \sum_j \sum_i y_{i,j,k} . hp_{j,k} . hl_k \qquad (13)$$

Where:

Y_k = total harvest from tree-based system k in entire landscape areas (ton)
$y_{i,j,k}$ = harvest from plot i, landuse system j, and productivity level j (ton ha^{-1})
$hp_{j,k}$ = harvesting efficiency, reflecting labour harvesting productivity in tree-based system k and productivity level j (ton person day-1)
hl_k = total labour allocated to tree-based system k calculated with Equation 4.

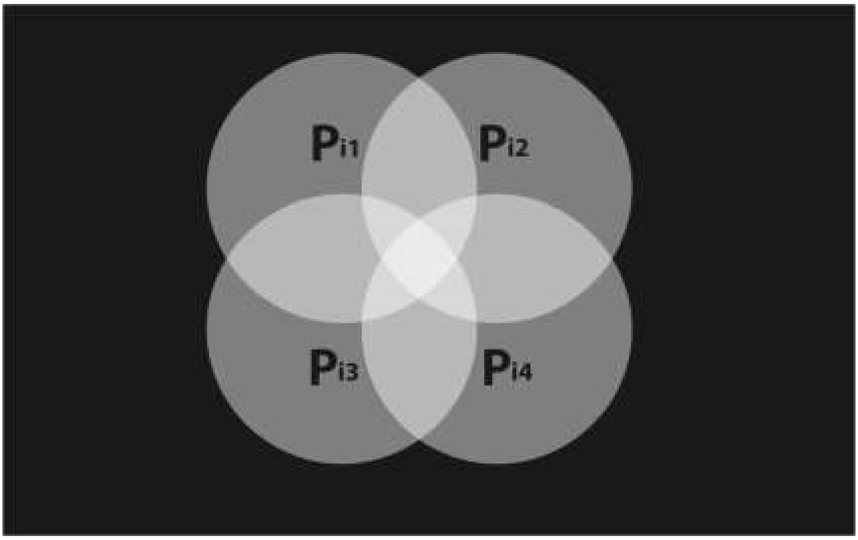
It is assumed that besides logged forest and non-timber yield, tree-based systems that can be harvested are all plots in the observed landscape. For logged forest and non-timber yield, harvesting location is determined by the procedure of land expansion described in Appendix 3.

Part of harvest yield is for domestic consumption. The rest will be kept in the storehouse or brought to the market. The decision to sell the surplus is determined by the probability to sell. The income after reduced by total cost will become financial capital.

Appendix 10

Estimation of the impact of land use change to biodiversity

The purpose of constructing this toolbox is to estimate the amount of species or species group that exists in a landscape. Suppose that pi,j is the probability that species i is found in a plot with habitat type j and the observed landscape contains several habitat types:



The probability that species i is found in the landscape (P_i) is the area with grey colour, which is an affiliation of the probability that species i is found in habitat types that compose the landscape (pij). This area can be calculated as 1 minus the black areas which is the intersection of probability values that species i is found in each habitat type that composes the landscape ($\overline{p}_{ij}$).

So:

$$P(\bigcup_{j=1}^{N} p_{ij}) = 1 - P\left(\bigcap_{j=1}^{N} \overline{p}_{ij}\right) \quad (14)$$

Or:

$$P(\bigcup_{j=1}^{N} p_{ij}) = 1 - \prod_{j=1}^{N} \overline{p}_{ij} \quad (15)$$

If the habitat type j consists of aj pixel, we can express Equation 15 as:

$$P(\bigcup_{j=1}^{N} p_{ij}) = 1 - \prod_{j=1}^{N} \overline{p}_{ij}^{\,a_j} \quad (16)$$