EnLiFT Model 1.0:

a household income and food security model for rural areas of Nepal

A Manual

Rachmat Mulia, Betha Lusiana,
Edwin Cedamon, Ian Nuberg, Yuba Raj Subedi

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World Agroforestry Centre
Southeast Asia Regional Program
Jl. CIFOR, Situ Gede, Sindang Barang, Bogor 16115
PO Box 161 Bogor 16001, Indonesia
Tel: +(62) 251 8625 415
Fax: +(62) 251 8625 416
Email: icraf-indonesia@cgiar.org
www.worldagroforestry.org/region/southeast-asia

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Preface

Agroforestry and community forest have been recognized as important systems to support livelihoods of many rural farmers in the Nepalese hills. Both are closely linked systems providing food, fodder, fuelwood, grazing, timber and non-timber forest products. However, the management of community forests and agroforestry systems, particularly in the Middle Hills, is sub-optimal and livelihood outcomes remain limited and inequitable with the result that poverty and food insecurity are widespread. Factors that impede the ability of community forestry and agroforestry systems to provide adequate livelihoods are complex and manifold and are situated in social, cultural, political, economic and ecological domains. Within this context, understanding systematically how agroforestry and community forests contribute to the livelihood and food security of farmers in the Nepalese hills is important.

A simulation model can help in providing systematic understanding and quantification of agroforestry-community-forest-people-livelihood-food security interactions, on which sensible management strategies can be formulated and implemented. This is the objective of the development of EnLiFT model version 1. Based on the interactions, the model makes a projection of household income derived from different livelihood options, both on-farm and non-farm, and the household food security level. The latter is defined as the ratio between the household expenditure capacity and the poverty line.

The model and this manual have been developed through collaboration amongst three institutions. World Agroforestry Centre (ICRAF) was responsible to develop a simulation model that can represent the main components and interactions within different agroforestry and community forest practices in mid-hills of Nepal as well as other sectors contributing to household income and food security, based on comprehensive investigation and documentation to various agricultural and forestry systems in the region by the University of Adelaide and Forest Action Nepal. Valuable comments and suggestions for model's improvement were also given by numerous experts especially Bishnu Hari Pandit and Swoyambhu Man Amatya from Nepal Agroforestry Foundation. The study and modelling activities were funded by the Australian Centre for International Agricultural Research (ACIAR) through the Enhancing livelihoods and the food security from agroforestry and community forestry in Nepal (EnLiFT) Project.

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Authors

Betha Lusiana
World Agroforestry Centre (ICRAF), Southeast Asia program,
Bogor, Indonesia

Edwin Cedamon
The University of Adelaide, School of Agriculture,
Food and Wine, Urrbrae, South Australia

Ian Nuberg
The University of Adelaide, School of Agriculture,
Food and Wine, Urrbrae, South Australia

Rachmat Mulia
World Agroforestry Centre (ICRAF), Southeast Asia program,
Bogor, Indonesia

Yuba Raj Subedi
Forest Action Nepal,
Lalitpur, Nepal

INTRODUCTION

What is EnLiFT model?

It is a tool to estimate household income and food security level in rural areas of Nepal, particularly the mid-hills region that has a rugged terrain with high variability in terms of biophysical and socio-economic condition, and local people that largely depend on farming system for their subsistence. The model can estimate household income derived from different livelihood options, both on-farm and non-farm, and their food security level. On-farm sector is represented by income from agricultural, agroforestry, and community forest lands.

Who can use EnLiFT model?

ENLIFT model was built using a STELLA modelling environment that allows model users to look at the model structure and if they wish to modify the structure. The model can be used by researchers or students that want (i) to quantify the contribution of community forestry and agroforestry systems to the livelihood and food security of the people in the landscape and (ii) to help local authorities in developing optimal landuse and livelihood strategy, to help smallholder farmers increase their livelihood.

Structure of the manual

The manual aims to provide users with descriptions of the EnLiFT model including its main assumptions and processes. The 1st section provides the background of the model. The 2nd section provides the basic overview of the model, while the 3rd provides detail structures and equations used in the model. The list of data required and results that can be derived from the model are available in the annexes.

MODEL OVERVIEW

Model platform and time step

The EnLiFT model was developed using Stella programming environment and operates in yearly time step since agricultural production cannot be practically simulated at a daily time step. It has a link with an Excel file that contains information on the demographic and socio-economic characteristics of the household. The model make projection of income and food security at househol level. Figure 1 shows the interface of the model, and Annex 1 provides a brief description on Stella modelling technique and the way to communicate between the Stella and Excel file.

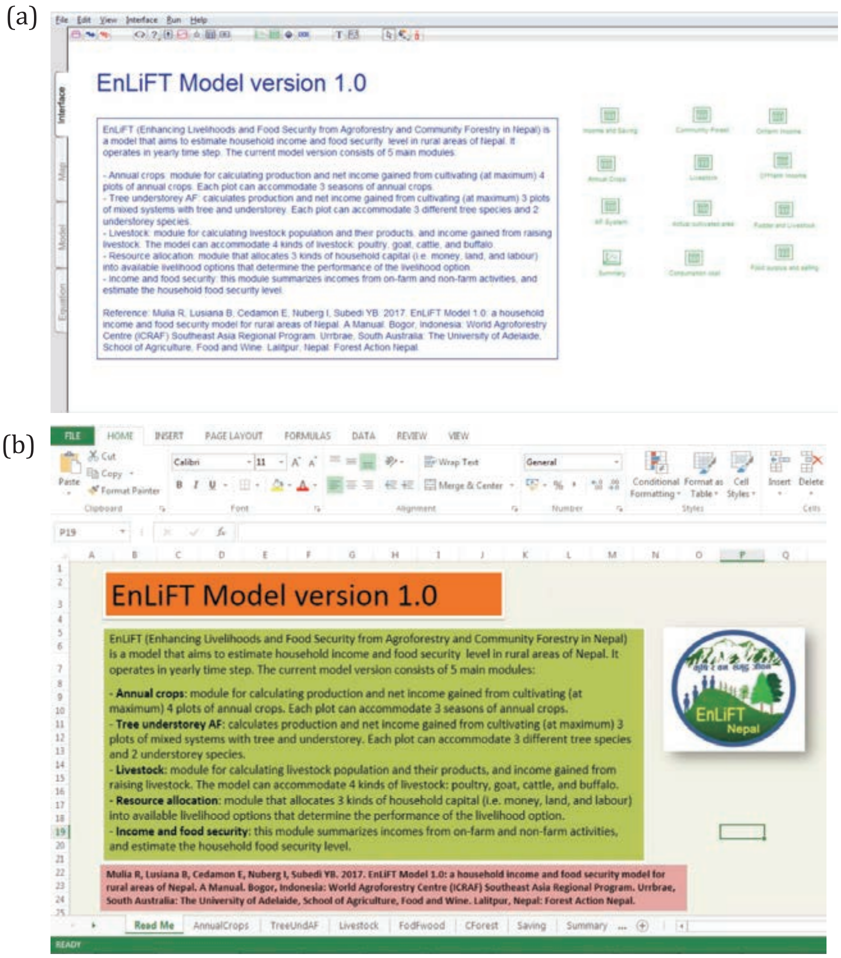


Figure 1. Interface of EnLIFT model 1.0 in (a) Stella platform and in (b) MS Excel that provides input parameter values for the Stella model.

Main modules

The EnLiFT model simulates different household activities that represent the household strategies in providing foods, access, and use of foods as well as generating cash income. The activities include:

- Cultivating annual crops in different plots and several seasons per year, with various annual crops for each season.
- Cultivating tree-based system, with or without understorey, or intercrops in the same plot as a mixed-system or agroforestry. The tree species can vary e.g. those for timber, fodder or NTFP purpose, with arrays of plants as understorey or intercrops.
- Raising different types of livestock for example poultry, goat, cattle or buffalo and derive income from selling the livestock or their products into the market; such as milk, derivative milk products (candy, chees), or eggs.
- Collecting products from community forest such as fodder or bedding materials for livestock, firewood for cooking or processing milk product, or timber for construction.
- Getting income from non-farm sourcess such as remittance, pension, or skilled jobs and using the income for food and non-food expenses such as for education and health.

To accomodate all of these activities, the model has been designed with five main modules: Annual Crops, Tree and Understorey (for tree-based or mixed system such as agroforestry), Livestock, Resource Allocation, and Income & Food Security.

The main purpose of the main modules are:

- Annual crops: to simulate production and net income gained from cultivating a maximum of 4 plots of annual crops. Each plot can grow 3 seasons.
- Tree understorey AF: to simulate production and net income gained from cultivating a maximum of 3 plots of tree-based or mixed systems with intercrops or understorey. In each plot, 3 different tree species and 2 understorey/intercrop species can be planted.
- Livestock: to simulate population and income gained from raising livestock. The model can simulate a maximum of 4 kinds of livestock for example poultry, goat, cattle, and buffalo.
- Resource allocation: to simulate how farmers allocate financial, land, and labour into different livelihood options based on household resource allocation strategy.
- Income and food security: summarizes incomes from on-farm and non-farm activities, and estimate the household food security level.

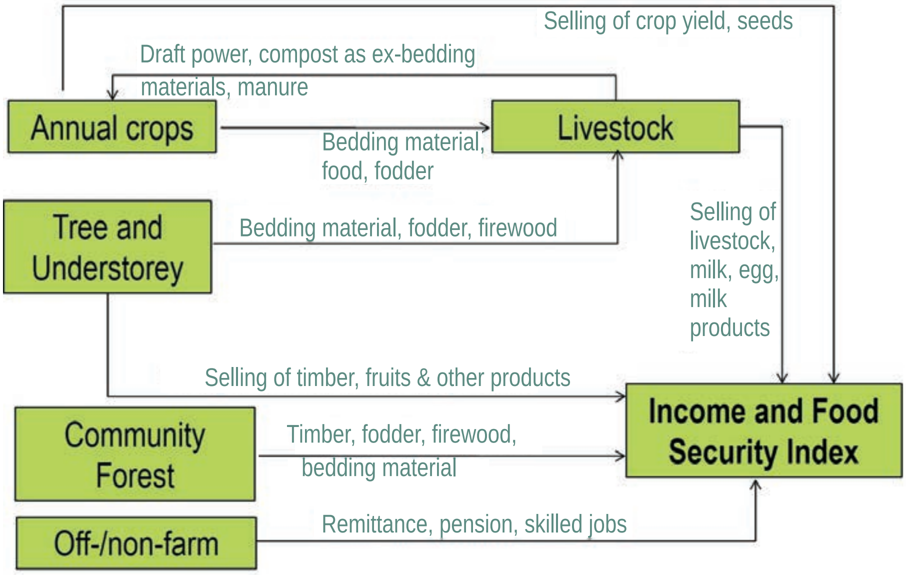


Figure 2. Flow and interaction between modules in the EnLiFT model version 1.0 constrained by household capitals and resource allocation.

Figure 2 describes the flow of products and activities between modules resulting as described in the resource allocation module resource allocation. In addition to the five main modules described above, the model also has a module that simulates the extraction of different products such as bedding materials, fodder, firewood, or timber from a community forest in case the household experiences a shortage. It also has a module estimating income contribution from non-farm sources such as remittance, pension, or skilled jobs. Annex 2-5 describe the list of input parameters related to each module.

Food security

Food security can be simply defined as the availability of food and the access to obtain those foods. The WHO describes three main aspects of food security: availability, access and uses; and the FAO adds the fourth aspect namely the stability of these three aspects across time. The World Summit on food security in 2009 officially stated that the four aspects of food security are the availability, access, utilization, and stability. The household activities described above can be categorized into the four aspects of food security:

- **Availability:** cultivation of annual crops, trees and understorey/intercrops and raising livestock to get yields and products
- **Access:** yields from annual crops, tree-based or mixed systems, and livestock products such as milk or egg can be used for household private consumption.
- **Use:** a fraction or all of the yields from the agricultural plots are used for private consumption

- **Stability:** the household landuse and livelihood strategy will determine the stability of agricultural and livestock outputs across time, including the amount of income and food security level.

Model dynamics

The model allows input parameters such as land area, product price and also the yield of tree and understorey component to be dynamics across time depending on the growth and production stage. The current model version allows the temporal variation in landsize, price and yields across 25 years. The 25-year period considered as the common period for perennial plants such as tree to complete its productive cycle. This dynamic aspect in the model allows users to design different scenarios related to land allocation, market mechanism or plant productivity, for examples:

- **Land area:** price of certain agricultural project is projected to be higher in the next five years, with a planning from the local government to give a subsidy. In response to this projection, the households allocate more lands for the agricultural product in the 5th year of simulation.
- **Product price:** scenario of steady inflation in product price across the years.
- **Productivity:** the local government plans to introduce higher quality seedlings, or better planting and harvesting technique, and the yield after the program implementation is projected to be higher than produced by the current seedlings and plot management practice. The impact of climate change and variability or natural disaster can also be estimated here by setting different patterns and levels of plant growth and productivity across years.

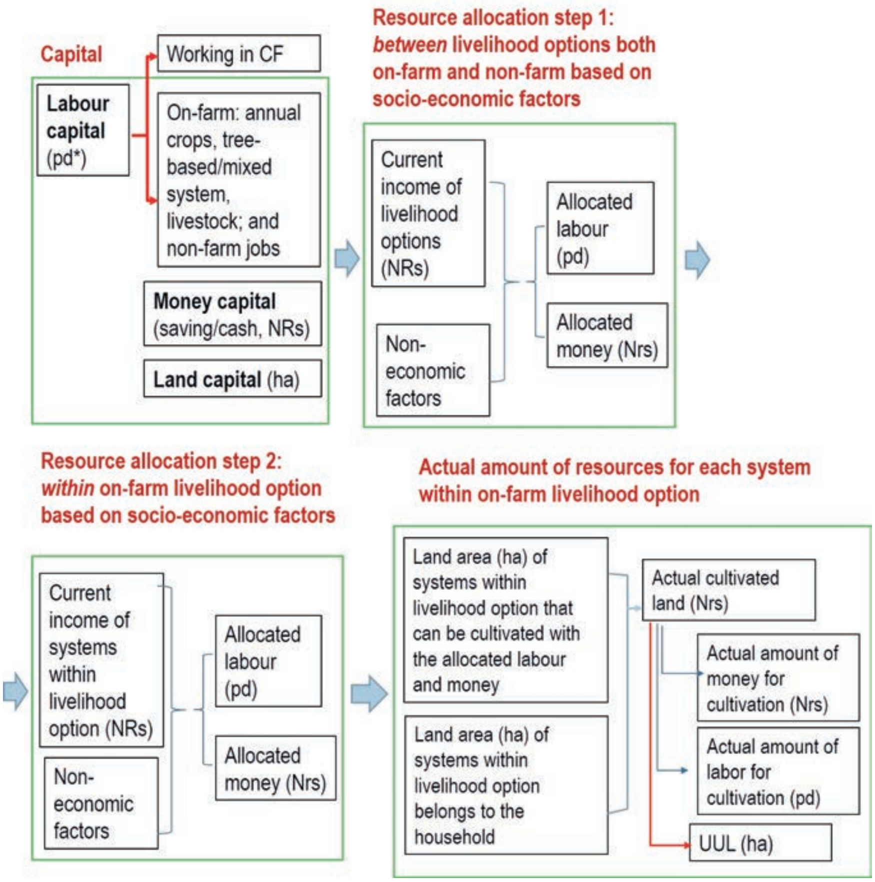
Stochasticity

The productivity of all agricultural and livestock products differs between model runs because of stochastic variation set in the model, within the range of ±10% from the input mean values. The stochasticity aims to capture the natural variation in plant and livestock productivity that occurs despite of the surrounding environment remains unchanged. The model only applies the stochastic variation to plant productivity level, and not to e.g. product price, since there is no such 'natural variation of product price'.

MODELLING CONCEPTS

Resource allocation

A household will allocate three main capitals, labour, financial and land, every year to each livelihood option namely annual crop, tree-based or mixed-system, livestock and non-farm jobs (Fig. 3). For labour capital, the available labour for on-farm and non-farm jobs is the total household person day minus that is allocated for communal works in community forest. Financial capital is represented by the current saving and/or cash money owned by the household, and the land capital is defined as the total area of lands managed by the household.



*pd = person day, CF=community forest, NRs = Nepalese rupees, ha = hectare, LU = landuse, UUL = under utilised lands.

Figure 3. Steps in resource allocation module that allocates three types of household's capital namely labour, money and land into on-farm and non-farm livelihood options. For the actual amount of resources in livestock system, it relates to labour, money and number of livestock instead of land area.

The allocation of available capitals to each livehood option depend on the expectation of future income gained from each livelihood options (economic factor) and farmers preference to choose a particular livelihood option or cultivating a certain farming systems (social factor). For example, some households may prefer to keep cultivating rice although it is less profitable compared to other crops because their family has been cultivating the same crops through generations. Another example, due to lack of knowledge in planting technique or plot management practice, some households also prefere cultivating crops that they are used to manage rather than new crops even though the latter are more economically profitable.

The resource allocation is calculated in two steps: (i) resource allocation between livelihood options and (ii) resource allocation within each livelihood option. **For the first:**

$$fb_t^i = \frac{\left(I_{t-1}^i\right)^{w_i}}{\sum_{i=1}^{4}\left(I_{t-1}^i\right)^{w_i}} \qquad (1)$$

Where fb_t^i is the fraction of resource allocation between livelihood options at year t for livelihood option i, I_{t-1}^i is income of livelihood option i at year t-1, wi is the socio-economic weighting factor (0= no economic considerationt to 1=full economic consideration). There are four livelihood options being considered: annual crops, tree-based or mixed system, livestock, and non-farm jobs (i=1-4).

The financial capital allocated to livelihood option i is thus:

$$M_t^i = fb_t^i * S_{t-1} \qquad (2)$$

With S_t as the saving and cash money owned by the household at year t-1. The labour allocation at year t is as follow:

$$B_t^i = fb_t^i * PD_t \qquad (3)$$

With PD as the total household person day at year t depending on the family size and members of family that stay outside home or work overseas. In this 1st step of resource allocation i.e. allocation between livelihood options only financial and labour allocation are considered.

The 2nd step relates to resource allocation for on-farm livelihood options. The financial and labour capitals will ultimately determine the maximum land area, or for livestock system determine the number of livestock that can be managed by the household (described below). The amount of money and labour allocated to the on-farm livelihood options will be further allocated to each system within the livelihood option as follow:

$$fwc_t^k = \frac{\left(I_{t-1}^k\right)^{r_k}}{\sum_{k=1}^{4}\left(I_{t-1}^k\right)^{r_k}} \qquad (4)$$

Where fwc_t^k is the fraction of resource allocation to annual crop system k at year t, I_{t-1}^k is income from the annual crop system k at year t-1, r_k is the weighting factor (0= no economic considerationt to 1=full economic consideration), and k is index for the four simulated annual crop systems (k=1-4). Similar principle applies to tree-based or mixed-system:

$$fwa_t^j = \frac{\left(I_{t-1}^j\right)^{r_j}}{\sum_{j=1}^{3}\left(I_{t-1}^j\right)^{r_j}} \qquad (5)$$

With fwa_t^j as the fraction of resource allocation to tree-based or mixed system j at year t, I_{t-1}^j is income from the tree-based or mixed system j at year t-1, r_j is the weighting factor (0= no economic considerationt to 1=full economic consideration) and j is index for the three simulated tree-based or mixed systems. For livestock:

$$fwl_t^n = \frac{(I_{t-1}^n)^{r_n}}{\sum_{n=1}^{4}(I_{t-1}^n)^{r_n}} \qquad (6)$$

Where fwl_t^n is the fraction of resource allocation to livestock system n at year t, I_{t-1}^n is income from the livestock system n at year t-1, r_n is the weighting factor (0= no economic considerationt to 1=full economic consideration) and n is index for the four simulated livestock systems.

The amount of money allocated to annual crop systems as described in Eq.2, will be further allocated to each annual crop system as follow:

$$Mc_t^k = M_t^1 * fwc_t^k \qquad (7)$$

Mc_t^k is the amount of money allocted to annual crop systems k at year t. The same principle applies to tree-based or mixed systems:

$$Ma_t^j = M_t^2 * fwa_t^j \qquad (8)$$

And livestock system:

$$Ml_t^n = M_t^3 * fwl_t^n \qquad (9)$$

Labour allocated to each annual crop, tree-based or mixed, and livestock system are respectively:

$$Bc_t^k = B_t^1 * fwc_t^k \qquad (10)$$

$$Ba_t^j = B_t^2 * fwa_t^j \qquad (11)$$

$$Bl_t^n = B_t^3 * fwl_t^n \qquad (12)$$

Each on-farm systems has its own associated cost and labour for initial systems establishment. Constrained by those costs, the maximum land area that can be managed given the current financial and labour allocation can be determined. In the case of livestock systems, the allocated resources determine the maximum number of livestock that can be managed by the household. Therefore, the actual cultivated area of each annual crop system is as follow:

$$Ac_t^k = min\left(\frac{Mc_t^k}{Ec_k}, \frac{Bc_t^k}{Lc_k}, Ac_{t-1}^k\right) \qquad (13)$$

Where Actk is the actual area of annual crop system k at year t, Mc_t^k is the amount of money allocated to the system k, Ec_k is the establishment cost required to establish a unit area (e.g. one hectare) of annual crop system k, Bc_t^k is the allocated labour to the system k, Ec_k is the labour person day required to establish a unit area of annual crop system k, and Ac_{t-1}^k is the area of annual crop system k at year t-1 or household land holding area of that crop system k. For tree-based or mixed-system:

$$Aa_t^j = min\left(\frac{Ma_t^j}{Ea_j}, \frac{Ba_t^j}{La_j}, Aa_{t-1}^j\right) \qquad (14)$$

And for the actual number of livestock system that can be managed:

$$Nl_t^n = min\left(\frac{Ml_t^n}{El_n}, \frac{Bl_t^n}{Ll_n}, Nl_{t-1}^n\right) \qquad (15)$$

Thus, the financial and labour capital are the potential limiting factors for the actual cultivated area and number of livestock that the household can manage. When the available financial or labour capital is not sufficient for managing all the lands, the un-managed land is defined as under-utilised land (UUL). When the resource limitation occured for livestock systems, then the current livestock population will be reduced (a higher livestock mortality rate). In livestock systems, the model also simulates male and female livestock, and the model assumes equal resource allocation for male and female.

Annual crop income and productivity

Soil fertility

Soil fertility in the plots of annual crop is modelled using the Trenbath principle (1984, 1989) and van Noordwijk (1999) and measured in the scale of 1-5. First of all, the actual soil fertility level depends on soil type, natural recovery, and fertilizer application. Natural recovery is a function of maximum and actual soil fertility level (fertmax and fertact respectively) and half-time recovery (h1/2) namely the time needed for the soil to achieve half of the maximum fertility (Eq. 16). The maximum soil fertility level varies with soil types, and the most fertile soil will have 5 as maximum fertility level.

$$\delta_{recov} = \frac{(fert_{max} - fert_{act})^2}{(1 + h_{1/2}) * fert_{max} - fert_{act}} \qquad (16)$$

A unit decrease in soil fertility is equivalent to an amount of loss in soil organic matter (SOM). Based on this, soil recovery by external input such as organic or inorganic fertilizer can be modelled equivalent to an increase in SOM. The soil fertility thus can recover naturally or due to external inputs.

The soil becomes more depleted by time, and the depletion rate is a function of current soil fertility and constant depletion rate:

$$\delta_{dep,t} = fert_t * \varepsilon \qquad (17)$$

The default value for the constant for any soil type is 0.2 and the default maximum soil fertility is 5. So, if current soil fertility is 5 (i.e. at maximum level) then the soil depletion is 1. It means actual yield will equal potential yield since:

$$y_{act} = y_{pot} * \delta_{dep} \qquad (18)$$

If the current soil fertility level is 4 while maximum fertility is 5 and the constant depletion rate is 0.2, then the actual yield equals 80% of potential yield and so on.

The soil fertility dynamics in the plot of annual crop is:

$$fert_{act,t+1} = \min(fert_{max}, \max(0, fert_{act,t} - \delta_{dep,t} + \delta_{natrecov,t} + \delta_{fertrecov,t})) \qquad (19)$$

Which is a function of actual and maximum soil fertility, soil depletion and the two types of recovery. In tree-based or mixed system, due to the presence of trees that play an important role in SOM balance through e.g. litterfall in the aboveground or root decay in the belowground part, it is assumed that soil fertility is stable, no degradation, across time. Therefore, the soil fertility dynamic is only modelled for the case of annual crop systems.

Soil ploughing

The plots of annual crop are ploughed every year before cultivation using the draft power of current livestock e.g. from buffalo or cattle. Any shortage in draft power will be filled from external source for example by renting from neighbours with/without a renting rate.

Fertilizer and agro-chemical application

The model allows the use of both inorganic and organic fertilizer, and agrochemical products such as pesticide or herbicide as part of plot management for annual crops. Organic fertilizer is modelled to come from three sources: leftover crop biomass, leftover bedding materials, and livestock manure. A fraction of crop residue will also be used as fodder and bedding materials for livestock.

Crop yield

Actual crop yield depends on soil fertility level and potential yield as described earlier (Eq. 18). The yield is firstly used for private consumption and seedling prepartion for next year cultivation. In case of surplus, a fraction of it will be used for livestock feeding and the rest for the market. Shortage in private consumption requires buying in the market. If the seedling requirement cannot be satisfied by the fraction of crop yield, the shortage can be overcome by e.g. buying seeds in the market. The model takes into account the seedling preparation cost that represents all costs necessary to process the fraction of crop yield into seedlings ready for cultivation.

Income

The model determines the production cost as the sum of cost for seedling preparation, buying seeds, buying inorganic fertilizer, agrochemical products, renting cost of draft power, labour cost and 'other' costs which are not covered by the mentioned costs. The revenue comes from selling annual crop products and net income is simply the revenue minus the total production cost.

Income and productivity of tree-based and mixed system

Propagule demand

Unlike in the case of annual crops, the households do not produce their own tree and understorey seedlings or propagules. The model assumes that the total demand will be satisfied by buying in the market.

Yield and private use

Tree components in the system can represent timber tree species, fruit tree or those producing non-timber forest products such as fodder tree species. Therefore, the yields from the system can be tree fruits, timber, or products such as bedding materials, fodder, and firewood. In case of mixed system, the yields include products from understorey or intercrops. All products will be firstly allocated for domestic uses, and the surplus is for sales in the market except for bedding materials, fodder and firewood. In case of shortage, the household will satisfy the demand by collecting the products from nearby community forest or buy in the market.

Income

Production cost for developing tree-based or mixed system includes cost for labour, seedling or propagule demand, and 'other' costs. Income is derived from selling fruit, timber, and products from understorey or intercrop.

Livestock population and income

Population

The population of livestock is dynamic over time due to annual birth and mortality rate. The model assumes, for some livestock types, there is a threshold representing the minimum number of livestock that the households is able manage. For example, in the households of certain socio-economic status, it's necessary to raise at minimum one cattle. The reason can relate to cultural or livelihood purpose. In case the minimum threshold is not met, the households will satisfy from the market. When the livestock population reach the maximum threshold, a fraction of livestock population will be for sales in the market. For feeding, the livestock will need fodder and other alimentary types, and for their stable, they need bedding materials. All of these requirements will be firstly satisfied by the products from annual crop and tree-based or mixed system. For each livestock type, the model simulates the case of male and female, with their specific characteristics and requirements.

Production

The products from the 4 types of livestock include manure, draft power, egg, milk, and milk processed-products like curd. For manure, it will be used as supplementary organic matter for plots of annual crops whereas egg or milk will be firstly used for private consumption before selling into the market.

Income

The total production cost includes cost for buying alimentary, for buying new livestock in case the minimum threshold is not met, cost for processing milk into derivative products, and cost for harvesting fodder or bedding materials in the community forest. Income is obtained from selling the livestock and the livestock products.

Community forest

As described earlier, in case the household demand on products such as fodder, firewood, or bedding materials cannot be satisfied by their own farming systems, they can collect a fraction of the shortage in nearby community forest, and the rest is satisfied from the market. For timber shortage, the household can buy timber from the community forest or in the market. The model takes into account the cost of collecting fodder, firewood, and bedding material from the community forest.

The model can also be used to simulate silviculture practice or innovation in the community forest mainly with its tree-based system module. Different types of tree species, both timber and non-timber, are possible to consider as part of the system with their corresponding contribution to the household income. The practices of mixed-system where trees are combined with annual crops or understoreys in the early years of plantation before the close of canopy, are also possible to simulate with the model, since it allows different annual crop/understorey species to integrated into the silviculture systems.

Income from off-/non-farm jobs

From the off-/non-farm sector, the household can obtain income from remittance, pension, and/or skilled jobs. The number of family member that contributes to the household income through remittance can vary across years.

Expense for food and non-food

Beside those supplied from the on-farm systems, the model also takes into account the expense that the household uses to obtain other types of foods either for primary or secondary consumption. For non-food expense, it consists of those spent for education, health, or other things classified as non-food.

Food security index

In the model, food security index is measured as the ratio between the household expenditure capacity and the poverty line (Eq. 20). The first covers two components namely the total cash income that the households can generate from the different livelihood options, and the money equivalence to their private consumption. The second i.e. the poverty line follows the minimum annual income per capita set by the government, and for household level, multiplied by the family size.

$$FS_t = \frac{EC_t}{PL_{Ref}} \qquad (20)$$

Based on the equation, the food security level below a unit value can be interpreted as 'really insecure' since the expenditure capacity is below the poverty line, 1-1.5 as 'insecure' since the expenditure capacity is relatively close to the poverty line, 1.5-2 as 'secure', and greater than 2 as 'really secure'. This food security level will vary across time depending on the household activities, performance of farming systems, and income from other livelihood options.

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ANNEXES

Annex 1. Description of Stella programming language

Stella is a programming language that uses diagram and icons (i.e. not lines of command like in other programming languages) to represent and simulate a dynamic and complex system (Shiflet and Shiflet 2006). In Stella, the modellers 'draw' their concepts by linking different icons and establish the relationship between them to represent the system components, function and interaction between the components.

The software has four different layers namely interface, model, map, and equation layer (Fig. 4). In the interface layer, the modellers can briefly inform about their model and provide tables for input or output paramater values. This layer can contain several pages and used to communicate with the users.

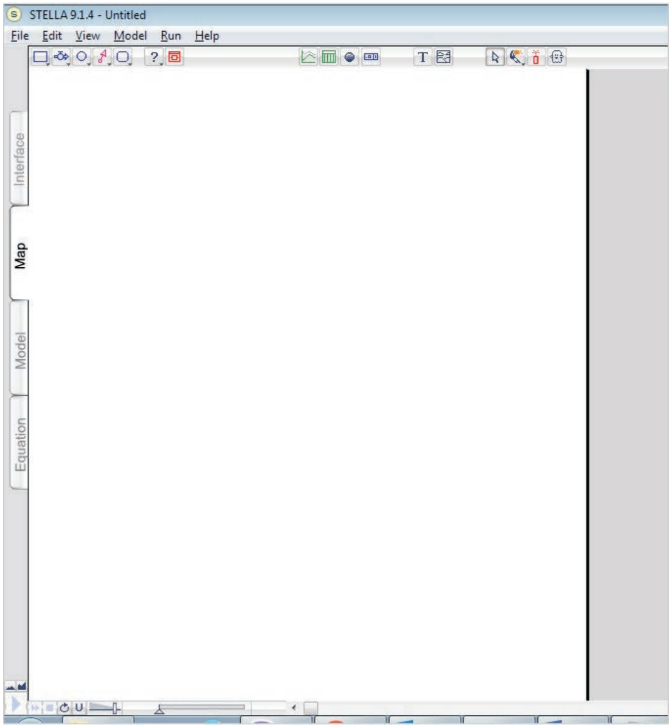
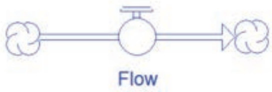
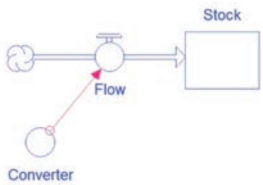


Figure 4. Four layers in Stella version 9.0 namely interface, map, model and equation.

The layer to make and store the modelling code is the model layer (Fig. 4). In this layer, the modellers can use four basic building icons or building blocks (Table 1) to represent system components and build relationship between them. Each icon has a specific function.

The model's diagram can also be seen in the map layer. In this layer however, the modellers or users cannot modify the code or anything. It's function is just to display the diagram, while to modify, it should be done in the model layer. Figure 5 shows the model layer of annual crop module in the EnLiFT model version 1.0.

Table 1. The four building icons or blocks in Stella programming.

Icons	Name	Function
	Stock	It is like a store that accumulates what flows into and drains what flows out. In Stella language, it is equivalent to a 'noun'.
	Flow	It defines what flows in or flows out from a stock. It is an action or 'verb'.
	Converter	It converts, stores equation or constant, but does not accumulate like stock.
	Connector (i.e. the red arrow)	It connects the system components represented by stock, flow or converter. It established relationship between system components.

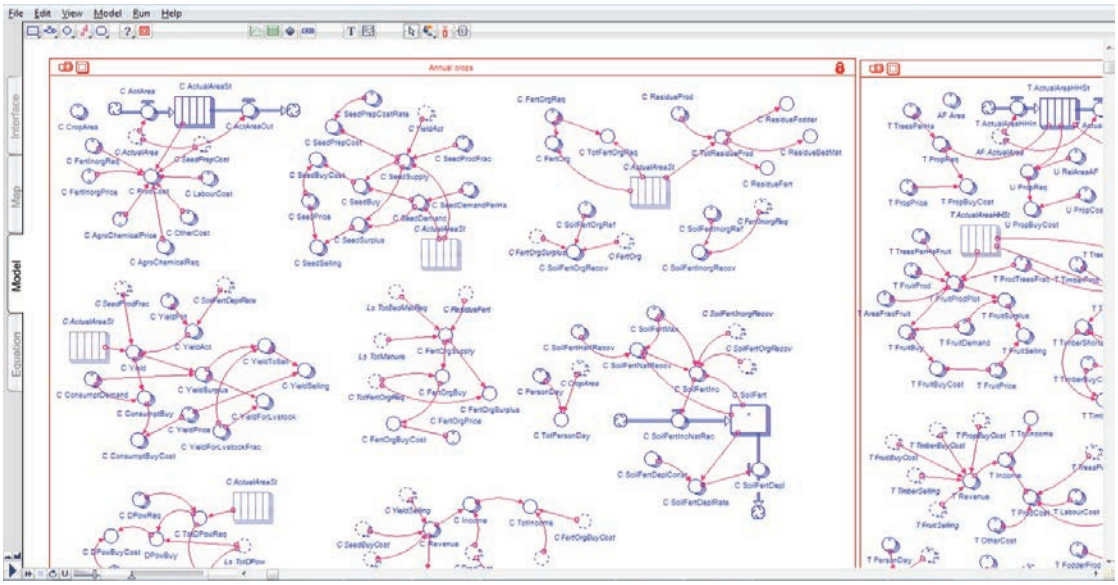


Figure 5. The model layer of annual crop module in the EnLiFT model version 1.0.

The stock, flow or converter can contain equations and the Stella software will automatically list all equations in the equation layer. Figure 6 shows the equation layer of the EnLiFT model version 1.0.

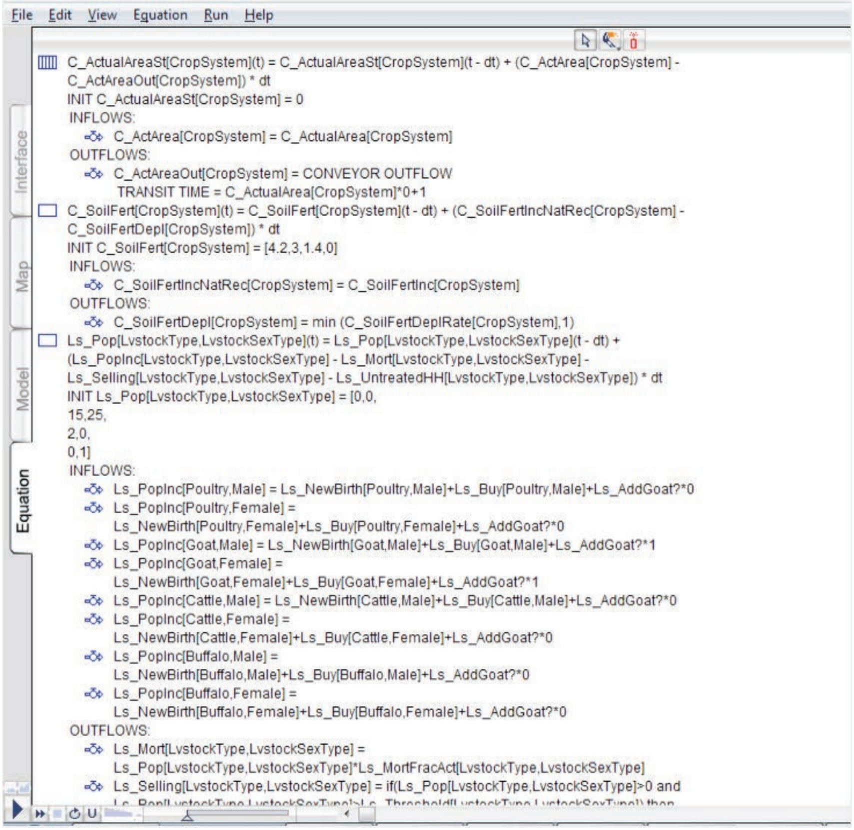


Figure 6. The equation layer of the EnLiFT model version 1.0.

The model simulation results can be displayed in three different ways namely in table, graph or single numeric display. The data in the table can be exported to display in another software like MS Excel. The graphs can be saved in common image file formats like jpeg or tif. Figure 7 shows an example of output table and graph from the EnLiFT model version 1.0.

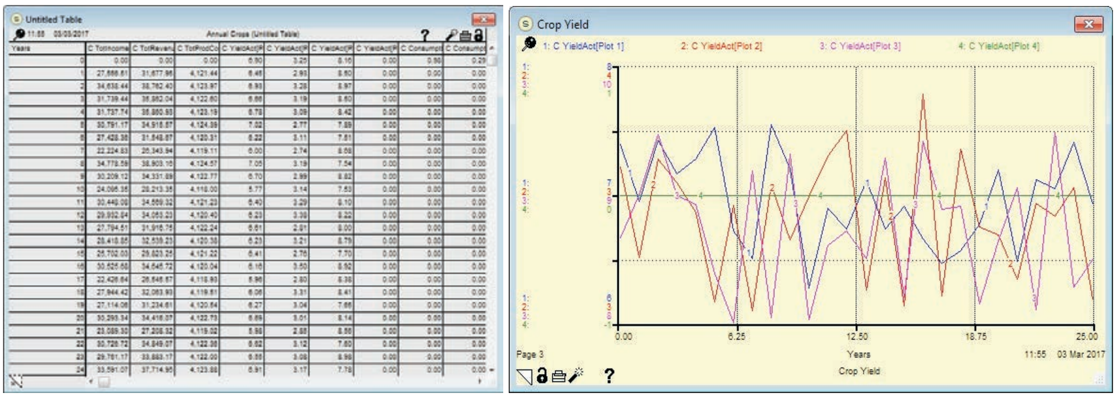


Figure 7. Example of model simulation results reported in (a) table and (b) graph with the Stella version 9.0.

How to link Stella and MS Excel

As described earlier, the EnLiFT model version 1.0 stores input parameter values in an Excel file and links the input file to EnLiFT Stella. To establish the link, the modellers should select Edit and Import Data from the menu bar, and a dialog box like shown in Figure 8 will appear. The Excel file that contain input parameter values can be speficied by browsing the Import Data Source and specify the Worksheet Name. For example, in the EnLiFT model version 1.0, all input paramaters and their values are stored in a sheet named 'StellaLinks' and they are arranged in rows with parameter names on the first colum and their values on adjacent column(s) (Fig. 8). Another possibility to arrange the input parameter values is by column with names of parameter in the first row and the values in next row(s).

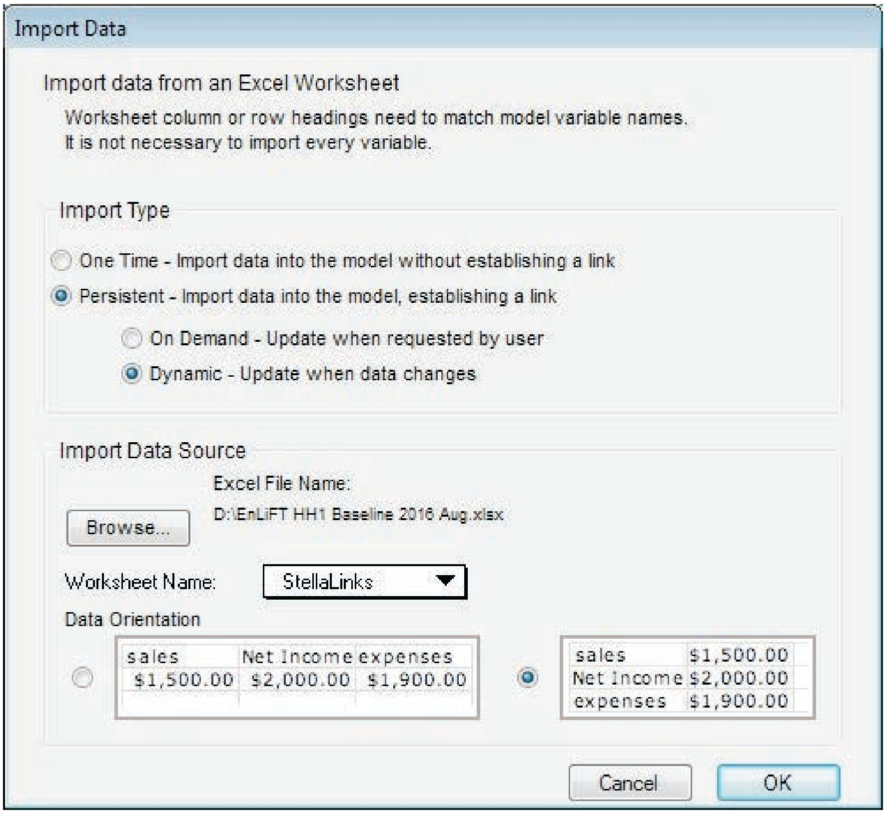


Figure 8. Dialog box to establish the link between Excel and Stella file.

For a more detailed description of Stella programming language and its features, the modellers can see Shiflet and Shiflet (2006) or the software website http://www.iseesystems.com/

Annex 2. Input parameters for annual crop module

Category	Parameter name	Unit*	Description
Plot management	C AgroChemicalReq	litre ha^{-1}	Amount of required agro-chemical product
	C FertOrgReq	ton ha^{-1}	Amount of required organic fertilizer
	C FertInorgReq	ton ha^{-1}	Amount of required inorganic fertilizer
	C DPowReq	days ha^{-1}	Required draft power
	C PersonDay	pd ha^{-1}	Total required person day per year
Yield	C YieldPot	ton ha^{-1}	Potential yield (at maximum soil fertility)
	C ConsumptDemand	ton	Household consumption demand of crop yield
	C YieldForLvstockFrac	[ ]	Fraction of crop yield for livestock feed
	C ResidueProd	ton ha^{-1}	Crop residue production
Seed production	C SeedDemandPerHa	ton ha^{-1}	Annual seed demand
	C SeedPrepCostRate	NRs ton^{-1}	Cost for preparing seeds
	C SeedProdFrac	[ ]	Fraction of yield for seed production
Soil fertility	C SoilFertInorgRef	ton ha^{-1}	Amount of inorganic fertilizer input (ton ha^{-1}) for one unit increase in soil fertility (i.e. for soil recovery)
	C SoilFertOrgRef	ton ha^{-1}	Amount of organic fertilizer input (ton ha^{-1}) for one unit increase in soil fertility (i.e. for soil recovery)
	C SoilFertHalfRecov	year	Recovery time to achieve half of maximum fertility
	C SoilFertMax	[ ]	Maximum soil fertility index (1=not fertile - 5=most fertile)
	C SoilFert	[ ]	Initial soil fertility index (1=not fertile - 5=most fertile)
Cost	C OtherCost	NRs ha^{-1}	Other cost (excluding fertilizer, seed preparation and labour)
	C LabourCost	NRs ha^{-1}	External labour cost
Crop area	C CropArea plot i	ha	Area of annual crop plot i
Yield price	C YieldPrice plot i season j	NRs ton^{-1}	Price of crop yield plot i season j
Seed price	C SeedPrice plot i season j	NRs ton^{-1}	Price of crop seed plot i season j
Other price	C DPowPrice	NRs day^{-1}	Price of draft power
	C AgroChemicalPrice	NRs $litre^{-1}$	Price of agrochemical product
	C FertInorgPrice	NRs ton^{-1}	Price of inorganic fertilizer
	C FertOrgPrice	NRs ton^{-1}	Price of organic fertilizer

*pd=person day, ha=hectare, [ ]=dimensionless (no unit), NRs=Nepalese rupees.

Annex 3. Input parameters for tree-based and mixed-system module

Category	Parameter name	Unit*	Description
Tree component			
Plot management	T TreesPerHa	tree ha^{-1}	Trees per hectare
	T ProdTreesFrac	[ ]	Fraction of productive trees in the plot
	T AreaFrac	[ ]	Area of each tree type relative to plot area
	T PersonDay	pd $tree^{-1}$	Total required person day per year
Yield demand	T FruitDemand	ton	Household demand on tree fruit
	T TimberDemand	m^3	Household demand on timber
	T TimberBuyCFFrac	[ ]	Fraction of timber from CF in case of shortage
	T TimberCFHarvCost	NRs m^{-3}	Cost of collecting timber from CF in case of shortage
Production	T BedMatProd	ton $tree^{-1}$	Production of bedding materials for livestock
Understorey and intercrop component			
Plot management	U RelAreaAF	[ ]	Relative area of understorey to total plot area
	U PersonDay	pd ha^{-1}	Total required person day per year
Yield demand	U YieldDemand	ton	Household demand on understorey yield
Production	U BedMatProd	ton ha^{-1}	Production of bedding materials for livestock
Both components			
Plot area	Area plot i	ha	Area of plot i
Fodder	T FodderProd plot i	ton $tree^{-1}$	Fodder production of tree plot i
Firewood	T FwoodProd plot i	ton $tree^{-1}$	Firewood production of tree plot i
Fruit	T FruitProd plot i	ton $tree^{-1}$	Fruit production of tree plot i
Timber	T TimberProd plot i	m^3 $tree^{-1}$	Timber production of tree plot i
Understorey yield	U Yield plot i sp. j	ton ha^{-1}	Yield of understorey or intercrop plot i species j
Fruit price	T FruitPrice plot i	NRs ton^{-1}	Price of tree fruit plot i
Timber price	T TimberPrice plot i	NRs m^{-3}	Price of timber plot i
Propagule price	T PropPrice plot i sp. j	NRs $prop^{-1}$	Price of tree propagule plot i species j
	U PropCost plot i sp. j	NRs ha^{-1}	Price of understorey propagule plot i species j
Yield price	U YieldPrice plot i sp. j	NRs ton^{-1}	Price of understorey yield plot i species j
Other cost	T OtherCost plot i sp. j	NRs $tree^{-1}$	Other cost for cultivating tree plot i species j
	U OtherCost plot i sp. j	NRs ha^{-1}	Other cost of understorey plot i species j
Labour cost	T LabourCost plot i sp. j	NRs $tree^{-1}$	Labour cost for cultivating tree plot i species j
	U LabourCost plot i sp. j	NRs ha^{-1}	Labour cost of understorey plot i species j

*pd=person day, ha=hectare, [ ]=dimensionless (no unit), NRs=Nepalese rupees.

Annex 4. Input parameters for livestock module

Category	Parameter name	Unit*	Description
Male			
Population	Ls Pop	goat	Initial population
	Ls Threshold	goat	Minimum population
	Ls NewBirth	goat	Annual new birth
	Ls MortFrac	[ ]	Mortality fraction from population
	Ls SellingFrac	[ ]	Fraction of selling
	Ls FoodReq	ton $goat^{-1}$	Food requirement
	Ls FodderReqRate	ton $goat^{-1}$	Fodder requirement
	Ls BedMatReq	ton $goat^{-1}$	Annual requirement of bedding material
Cost	Ls PersonDay	pd $goat^{-1}$	Total required person day per year to raise 1 goat
	Ls OtherCost	NRs $goat^{-1}$	Other cost (beside for food)
	Ls LabourCost	NRs $goat^{-1}$	Labour cost of raising one goat
Production	Ls ManureProd	ton $goat^{-1}$	Annual manure production
Female			
Population	Ls Pop	goat	Initial population
	Ls Threshold	goat	Minimum population
	Ls NewBirth	goat	Annual new birth
	Ls MortFrac	[ ]	Mortality fraction from population
	Ls SellingFrac	[ ]	Fraction of selling
	Ls FoodReq	ton $goat^{-1}$	Food requirement
	Ls FodderReqRate	ton $goat^{-1}$	Fodder requirement
	Ls BedMatReq	ton $goat^{-1}$	Annual requirement of bedding material
Cost	Ls PersonDay	pd $goat^{-1}$	Total required person day per year to raise 1 goat
	Ls OtherCost	NRs $goat^{-1}$	Other cost (beside for food)
	Ls LabourCost	NRs $goat^{-1}$	Labour cost of raising one goat
Production	Ls ManureProd	ton $goat^{-1}$	Annual manure production

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