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Development and application of a bio-economic agroforestry model for the tropics.

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Introduction

In February 2007 agroforestry trials of enriched fallow were set up in participation with indigenous farmers in the Venezuelan Guyana shield region. To compare ex ante the economic sustainability of these trials with each other and vis-à-vis the traditional system on a one-hectare scale, a bio-economic agroforestry model was developed. The model allows analyzing whether the enriched fallows are economically an improvement of the traditional system, as they retain soil fertility, and hence productivity, and produce a marketable surplus of indigenous fruit. However, the anticipated increase in labour input will hamper adoption (Mercer, 2004).
To clarify why and how a proper model was developed, we review existing agroforestry models. Four types of models are identified. Bio-physical models, like Simile, HyPAR, SCUAF and WaNuLCAS, simulate yields by mechanistic equations. Economic models use existing or simulated yield data from bio-physical models to simulate profitability. Examples are the Agroforestry Calculator, ARBUSTRA and the Agroforestry Estate Model. Bio-economic models, like NUTMON, BEAM and Plot- and FarmSAFE, are a combination of the two previous ones.

Methodology

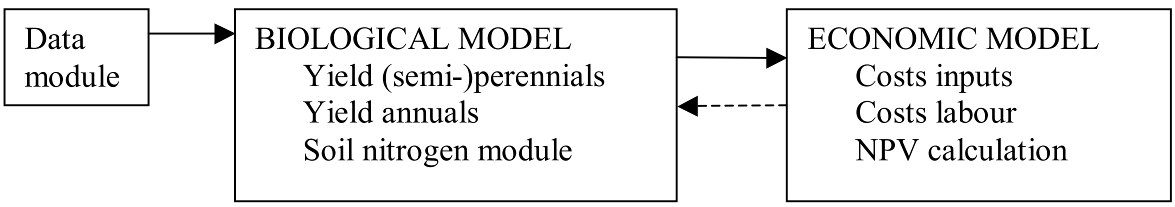

Figure 1. General model structure

Model structure
The model consists of a biological and an economic sub-model, interacting with one another as shown in figure 1. The data module provides bio-physical data, used in the biological model to calculate yields. The soil nitrogen module calculates yearly the nitrogen balance to account for the impact of nitrogen deficiencies on growth. The economic model determines the costs of input

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and labour, and uses the generated yield data to calculate benefits. Management decisions, like the use of fertilizers, pruning practices, etc., entered in the economic model, influence yields (dotted arrow).

Biological sub-model

Yearly biomass production is based on light incidence, but limited by nitrogen deficiencies in the soil: $(dB/dt)_t = (365 * I_t * f_t * \varepsilon * NI_t)/1000 - a * B_t$, with I_t mean daily radiation per year in MJ/m^2; f_t intercepted radiation [%]; ε radiation use efficiency [g/MJ]; NI_t the nitrogen stress factor (see below); a percentage biomass needed for respiration; and B_t biomass in year t. This equation is based on PlotSAFE (Van der Werf et al., 2007), though the water stress factor of PlotSAFE was replaced by a nitrogen stress factor, as nitrogen is more limiting in tropical conditions (Rao et al., 1998). The intercepted daily radiation is determined by the canopy structure and the leaf area index. The model divides the canopy in three layers; radiation not intercepted in an upper layer, is available to lower layers. Leaf area index growth is modelled as follows (Van der Werf et al., 2007): $(dL/dt)_t = \rho * N_t * (A_m\text{-}A_t)$. Hence the increase in leaf area index is the product of the number of shoots (N_t) at time t and the quantity of leaf area the shoot still needs to develop ($A_m - A_t$), multiplied with planting density (ρ) to become an index. The number of shoots increases proportionally with biomass, but is never higher than the maximum number of shoots. Finally harvest indices divide the produced biomass over a yearly harvested production of fruit, litter and pruning, and wood production, harvested at the end of the cycle. The model allows for fruit processing, generating an extra labour input.

If the nitrogen needs of the crops exceed the soil nitrogen content, a nitrogen stress factor reduces biomass growth proportionally with the nitrogen deficiency. The main equation governing soil nitrogen changes was adapted from NUTMON (Van den Bosch et al., 1998). Inputs of nitrogen into the soil are nitrogen fertilizer, atmospheric and non-symbiotic nitrogen fixation (both determined by precipitation), and nitrogen additions from litter and pruning. Nitrogen fluxes leaving the soil are determined by leaching (dependent on soil depth and clay content, and precipitation) and uptake of nitrogen by the crops.

Economic sub-model

Inputs, like fertilizers, insecticides and seeds, create variable costs; fixed costs are entered as well. The costs are accounted on a yearly basis or as a one-time cost (e.g. in planting year) by multiplying the quantity used with the frequency of use, the price and an inflation factor. The following labour input categories are included in the model: slash and burn, planting, nursery, maintenance, pruning, harvesting, cutting and processing. Labour costs are calculated per species per year by multiplying the labour input with the opportunity cost of labour and an inflation factor. Currently the model does not account for potential economies of scale. Finally some economic indicators, like the Net Present Value ($= \sum (b_t - c_t)/(1 + r)^t)$), infinite NPV ($=$ NPV $* (1 + r)^n/(-1 + (1 + r)^n)$) and EAV (= infinite NPV * r), cost benefit ratio and returns to labour are calculated (with n duration of the agroforestry cycle, b_t total benefits in year t, c_t total costs in year t and r the discount rate).

Results & discussion

Data

As the agroforestry trials were only recently set up, we dispose only of initial bio-physical values and the general trial set-up. Missing bio-physical values were generated by an extensive literature review, which was also used for model calibration. Labour and input data are deducted from Zent (1992) and Uhl (1980), who performed an in-depth analysis of the indigenous cultivation systems in the Venezuelan Amazon; and from socio-economic questionnaires and participatory review.

Production indicators

For reasons of brevity only two of the five enriched fallow systems are compared with the traditional slash and burn system. The traditional cycle starts with four year cultivation of corn (*Zea mays L.*) and yucca (*Manihot esculenta Crantz.*) followed by a 15 year fallow (fig.2). Trial 1 is a combination of copoazu (*Theobroma grandiflorum (Willd. Ex Spreng.) Schumm.*), cacao (*Theobroma cacao L.*) and ice-cream-bean (*Inga edulis Mart.*); while trial 2 is a more complex system of ice-cream-bean, copoazu, seje (*Oenocarpus bataua Mart.*), peach palm (*Bactris gasipaes Kunth*), manaca (*Euterpe oleracea Mart.*), cacao and temare (*Pouteria caimito (Ruiz & Pav.) Radkl.*). In both trials yucca and corn are intercropped on the traditional way in the first four years. The cycle's duration is set equal to the duration of the traditional system at 19 years.

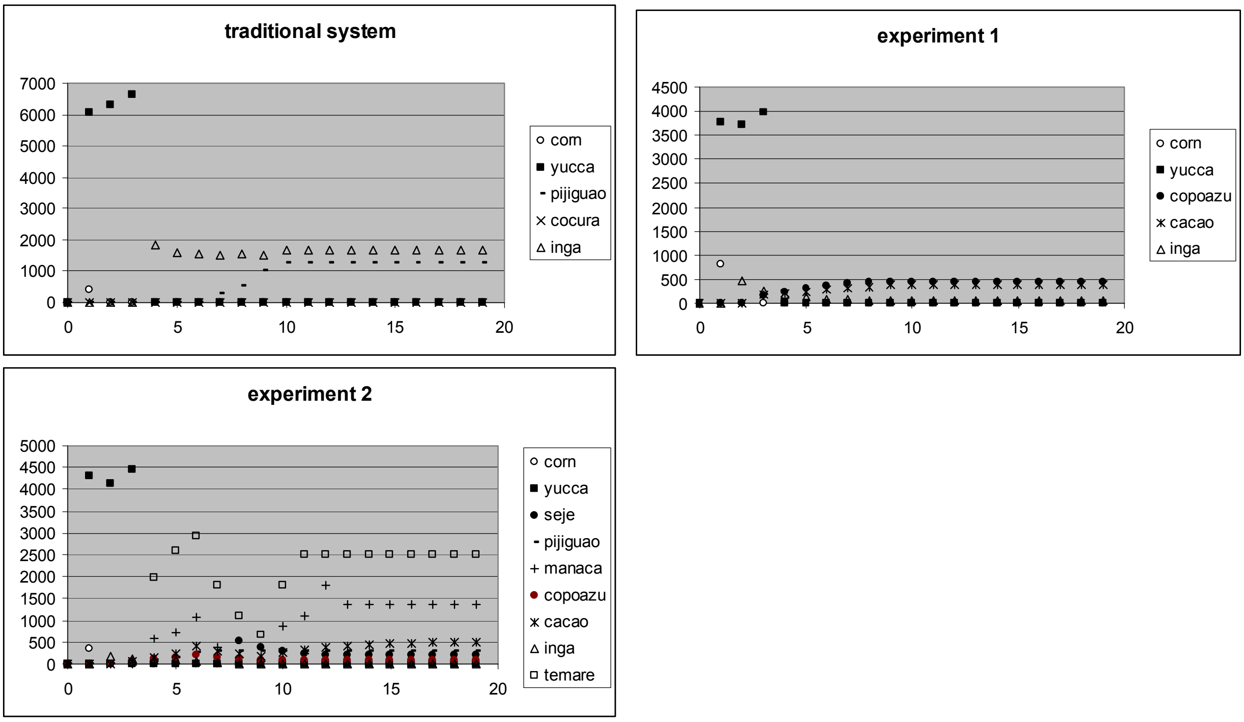

Figure 2. Predicted production data

Economic indicators

Table 1: Simulated economic indicators of the agroforestry systems under study

System	*B/C ratio*	*NPV (US$)*	*Return to labour (US$/day)*	Labour input (days)
traditional	1.47	2,322	5.54	2,118
1	1.8	2,641	3.56	1,303
2	3.16	9,446	6.2	2,398

All systems are profitable (table 1) when the complete cropping cycle is analyzed. The trials outperform economically the traditional system, as they generate a continuous flow of marketable produce after yucca cultivation has stopped. The high labour input of trial 2 compared to trial 1 is explained by the inclusion of palms. High density planting of labour intensive yucca is responsible for the high labour input of the traditional system. Yucca-derived products, as well as palm products fetch high prices on local markets, explaining the high returns to labour of the traditional system and trial 2. In the experimental systems soil fertility stabilizes at a certain level, due to the pruning practice and the planting of a relatively high density of the nitrogen fixating Inga. This means that if the shading effect is not too strong, farmers could continue yucca cultivation for more than four years.

Sensitivity analysis

A sensitivity analysis was performed on the main parameters of each module for the traditional system and system 1. In table 2 the NPV elasticities ((△NPV/NPV)/(△P/P)) for the most sensitive model parameters (P) are shown. Economic indicators have the largest impact on the NPV, as well as bio-physical indicators related to yucca cultivation, especially in the traditional system, and related to the main perennials, especially in system 1. The soil nitrogen module is robust.

Table 2: Results of sensitivity analysis on main parameters

parameter	Elasticity traditional system	Elasticity system 1
$\varepsilon_{main\_perennial}$	0.087	0.22
$A_{M,\ main\_perennial}$	0.074	0.2
HI_{yucca}	1.02	0.85
p_{yucca}	1.072	0.89
discount rate	-0.52	-0.6
Labour for maintenance	-0.0679	-0.097
p_{labour}	-0.2178	-0.338
$HI_{fruit,\ main\_perennial}$	0.054	0.15

Conclusions and outlook

The simulated net present values and benefit cost ratios are high, though comparable to results of similar agroforestry trials in Latin America (Current et al., 1995). The high values are explained by the extensive nature of the agricultural systems, and the hypothesis that everything is sold at market value, leading to high benefits. A high discount rate (r = 20%) is realistic, as short term benefits are highly valued by the indigenous.

To be complete the model needs to be extended to account for water limiting effects. The model will also be used to evaluate agroforestry trials in two other project countries, Brazil and Suriname. Therefore a stock module will be included, as the traditional Brazilian system includes stock breeding. Finally the model will be extended to account for a bio-energetic analysis, as valuing agricultural output and labour by their market value does not take into account their actual value in communities with limited commercial activities. The latter analysis will also allow accounting for the ability to strengthen food security, one of the MDGs, of each system.

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