Integrating systems-analytical and expert knowledge to quantify land use systems: a case study for the Northern Atlantic Zone of Costa Rica

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ABSTRACT

During the last decade land use models at various levels of scale and with different aims have received ample attention in literature. Sources of input data of these land use models, i.e. land use systems expressed in quantitative terms of inputs and outputs, received less attention. This paper describes two of such sources, i.e. so-called Technical Coefficient Generators, called PASTOR and LUCTOR, that quantify land use systems based on the integration of systems-analytical knowledge, standard agronomic and animal husbandry data, and expert judgement. PASTOR quantifies livestock systems while LUCTOR is geared towards cropping systems. Main inputs quantified include costs, labour, fertiliser use and application of crop protection agents. Outputs are *production and a number of associated sustainability indicators. Although both PASTOR and LUCTOR were developed to generate input data for land use models, they are also useful as stand-alone tools to explore the technical efficiency of land use systems, to perform cost-benefit analyses, and to quantify trade-offs between socio-economic and sustainability outputs at the field level. PASTOR and LUCTOR are illustrated with data from the Northern Atlantic Zone in Costa Rica. It is argued that expert knowledge is a crucial source of information and complementary to systems analytical knowledge in quantifying land use systems.*

Keywords: land use model, expert system, technical coefficient generator, sustainability

INTRODUCTION

During the last decade, various land use modelling studies have been executed to support policy decision making with respect to agricultural land use at different scale levels, varying from farm (e.g. Kruseman et al, 1995), settlement (e.g. Schipper et al., 1995), regional (e.g. Van Keulen & Veeneklaas, 1993), national (Veldkamp & Fresco, 1996), supra-national (e.g. Rabbinge & Van Latesteijn, 1992) to global (e.g. Penning de Vries et al., 1995). These studies have in common that they analyse economic, social and environmental aspects of land use in an integrated way by using tools based on quantitative systems analysis (Penning de Vries et al., 1992). Important building blocks of these tools are often quantitative descriptions of land use systems which may be any type of agricultural land use under specific biophysical and technological conditions associated with inputs and outputs (Fresco et al., 1992), which are called technical coefficients (TCs) in the current paper. For each land use system, e.g. cropping, timber plantation, cattle, etc., a unique quantitative combination of inputs results in a unique mixture of outputs. Inputs may include external nutrients (e.g. fertiliser), crop protection agents, labour use and agricultural implements. In addition to production in physical or financial terms, outputs may include indicators related to sustainability, such as changes in the natural resource stock (e.g. soil nutrients, soil organic matter), environmental pollution (e.g. soil nutrient losses, use of crop protection agents) and the emission of trace and greenhouse gasses. Quantifying trade-offs between socio-economic and sustainability outputs of land use systems is an important goal of many recent land use studies (Jansen et al., 1995; Bouman et al., 1998a).

Whereas land use studies received ample attention in literature, the issue of how to formalise the quantification of land use systems has hardly been addressed at all. This is unsatisfactory since i) the outcome of land use studies is often dominated by the involved land use systems, ii) quantification of land use systems usually involves major time and resource commitments, iii) *ex-ante* analysis of land use systems is an important step in evaluating the efficiency of proposed alternatives and in quantifying trade-offs that exist between economic and environmental objectives, and iv) integration and synthesis of information on land use systems is an important step to identify bottlenecks in existing knowledge that may direct disciplinary research agendas specifically, and the agricultural research agenda in general. Therefore, a closer examination of the concepts and procedures required to quantify land use systems is warranted. In this paper, concepts and principles are presented that are required to quantify land use systems in terms of TCs. A generic framework is introduced which is implemented in two so-called Technical Coefficient Generators (TCGs): PASTOR (PASture and livestock Technical coefficient generatOR) for cattle systems, and LUCTOR (Land Use Crop Technical coefficient generatOR) for cropping systems. PASTOR and LUCTOR were developed in the REPOSA[1] program with the Northern Atlantic Zone (NAZ) of Costa Rica as case study. PASTOR and LUCTOR build upon experiences gained in previous phases of REPOSA (Jansen & Schipper, 1995; Stoorvogel et al., 1995) and upon methodologies developed in related studies in The Netherlands (e.g. Habekotté, 1994), Europe (De Koning et al., 1995) and West Africa (Hengsdijk et al., 1996).

Bouman et al. (1998a) and Sáenz et al. (1998) demonstrated the use of TCs generated by PASTOR and LUCTOR in land use studies for the Northern Atlantic Zone at regional and farm level, respectively. This paper focuses on the underlying concepts used in PASTOR and LUCTOR, describing briefly their functioning, illustrating their use as stand-alone tools in the *ex-ante* analysis of land use systems, and discussing some benefits of the developed methodology.

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[1] REPOSA stands for Research Program on Sustainability in Agriculture, a co-operation between Wageningen Agricultural University (WAU), the Centre for Research and Education in Tropical Agriculture (CATIE), and the Ministry of Agriculture and Livestock, Costa Rica (MAG).

MAIN CONCEPTS USED IN PASTOR AND LUCTOR

Some of the terminology that is used in this section is summarised in Table 1.

Type of land use systems in different types of land use studies

Different types of land use models exist, each with their own purpose and spatial and temporal scales. Their aim determines to a large extent which type of land use systems must be quantified. In *long-term explorative studies*, e.g. as described in Bouman et al. (1998a), agro-ecological sustainable land use options are explored given societal objectives related to land use. Such studies require *alternative* land use systems that are technically feasible and sustainable from an agro-ecological point of view, but most likely not yet widely practised. It may be assumed that such systems use inputs more efficiently than current systems due to supposed future efficiency gains in agricultural production (de Wit et al., 1987). Furthermore, aspects related to sustainability of alternative land use systems can be operationalised in terms of a balanced nutrient supply; various external resources (e.g. fertiliser) balance nutrients withdrawn from the system. This implies that productivity of these land use systems is maintained over time.

Land use studies aimed at identification of possible *short term* effects of policy instruments related to land use have a shorter time horizon than explorative studies (e.g. Kruseman et al., 1995). In these studies, future efficiency gains as assumed in alternative systems are presumably less pronounced, and land use systems that represent current means of production need to be included in the analysis. Often, though not necessarily, such land use systems are unsustainable in terms of soil nutrient balances (i.e. they may be soil depleting). In this case, land use systems should represent *actual* land use systems and incorporate changes in production techniques that can be expected to be realised in the short-term only.

Quantifying technical coefficients

In both LUCTOR and PASTOR the so-called 'target oriented' approach is used (Van Ittersum & Rabbinge, 1997) for quantification of *alternative* production systems: target production levels are predefined and technically optimal combinations of inputs required to realise these target levels are subsequently quantified. For example, target production levels for crops and pastures may vary from maximum (i.e. potential), via close-to-actual situations to very low yields, resulting in simulated high and low external input levels (e.g. fertilisers, crop protection agents) for the first and the last case, respectively.

For quantification of *actual* production systems a descriptive approach is used. Primary data regarding inputs and physical production are obtained from field surveys, while remaining data gaps are estimated using standard agronomic and animal husbandry data and expert knowledge.

Sustainability indicators are calculated by bookkeeping of crop protection agents and nutrients in the system. Nutrient efficiencies and loss fractions are based on a combination of systems-analytical knowledge and expert judgement.

Substitution of different types of inputs is being accounted for to a limited extent. From a viewpoint of optimal resource allocation, one type of substitution that has to be taken into account is the one between labour and capital inputs (de Wit, 1979), implying that production techniques can be quantified using herbicides or manual weeding methods, or production techniques using manual or mechanised field preparation methods.

Both PASTOR and LUCTOR contain three categories of TCs: *i*) economic, i.e. costs of production and input requirements in physical terms: labour, fertilisers, crop protection agents and implements, *ii*) physical production (i.e. crop yield, meat, milk) and *iii*) sustainability indicators: soil nutrient balances for nitrogen (N), phosphorus (P) and potassium (K); nutrient losses to the environment via leaching, volatilisation and denitrification/nitrification; and use of crop protection agents. Input and outputs are expressed per hectare and are scale independent.

Costs for movable inputs (e.g. implements) are based on rent prices. To calculate the cost of immovable inputs (e.g. on-farm post-harvest processing unit, drainage canals) it is implicitly assumed that the scale of such inputs is economically optimal. Costs of production are expressed as an annuity factor to take account of investment costs in materials with a life span exceeding one year. Annuity costs are calculated using the capital recovery factor (Price Gittinger, 1973) with a discount rate specified by the user.

Complementary information sources

TCs are mostly based on standard data regarding agronomic and animal husbandry relationships, empirical data and systems-analytical knowledge of physical, chemical, physiological and ecological processes. In situations where data are incomplete, lacking or where processes are poorly understood, expert knowledge is used as a complementary information source. Though expert knowledge is sometimes considered to be an unreliable source of information in land use studies (Van Diepen et al, 1991), often decisions relating to land use are necessarily (partially) based on this type of knowledge since adequate formal knowledge is insufficient. For example, process-based models predicting the complex interactions between pests and crops and their effect on yields are not yet sufficiently developed for the wide generation of TCs (Kropff et al., 1995). This is due to the stochastic and location-specific nature of crop-pest complexes, which make effects on yields highly diverse and difficult to predict. At the same time such diversity is highly relevant from various points of view (e.g. economic, agronomic and political), thus leaving the land use systems modeller no other option but to 'guesstimate' the effects on yield of a reduced use of crop protection agents. In the development of both PASTOR and LUCTOR, teams of experts were consulted regarding their knowledge on livestock and cropping systems in the NAZ, resulting in many debate and well thought-through relationships to quantify TCs.

PASTOR

PASTOR (Bouman et al., 1998b) contains separate modules for the calculation of TCs for pastures, herds and feed supplement systems.

Pasture

The pasture module in PASTOR is able to quantify three types of pastures: (i) fertilised pastures and (ii) grass-legume mixtures; (i) and (ii) represent *alternative* systems that are sustainable in the sense that they have closed soil-nutrient balances; and (iii) unfertilised pastures that are a proxy for *actual* pasture management and that may be unsustainable in terms of soil nutrient balances. Pasture systems are characterised by a combination of environmental and management criteria: botanical composition (species), soil type, stocking rate, weeding manner and production level as determined by fertiliser application rate. Table 2 gives an example of implementation for the NAZ as used in a regional land use study (Bouman et al., 1998a).

For fertilised grasses, TCs are calculated with a pre-defined soil nutrient balance, i.e. maximum quantities of nitrogen (N), potassium (K) and phosphorus (P) to be removed from the soil are pre-defined by the user. For *alternative* sustainable pasture systems, soil nutrient balances are closed (i.e. set to zero). The procedure for calculating TCs involves schematically a number of steps (Figure 1). First, for each grass species, upper and lower production boundaries are estimated for each soil type in the study area in terms of biomass and contents of metabolisable energy (ME), crude protein (CP) and phosphorus (P). The upper boundary corresponds to the maximum attainable production with no nutrient constraints (Bouman et al., 1996), whereas the lower boundary corresponds to the minimum production level attained on exhausted soils where the grass just manages to survive. On the basis of the maximum attainable production, PASTOR calculates attainable feed (i.e. biomass and amount of ME, CP and P) on offer as function of a range of (user-defined) stocking rates. With increasing stocking rate, less of the pasture biomass is available for uptake because of trampling and deposition of faeces and urine (Van der Ven, 1992). Soil nutrient balances (N, P and K) are calculated using an adapted version of the model presented by Stoorvogel (1993). The calculations are based on estimates/calculations for all inputs, namely atmospheric deposition, fixation by micro-organisms, weathering, manure and urine (from the grazing stock), and all outputs, namely the attainable amount that may be removed by grazing and losses by erosion, leaching, volatilisation, denitrification/nitrification, and fixation (only for P). A negative balance indicates the amount of fertiliser that is needed to sustain the attainable amount of biomass that may be removed by grazing (i.e. on offer). Next, a user-defined range of fertiliser application levels is specified, ranging from 0-100% of the amount needed to sustain attainable feed on offer. Gross fertiliser input is calculated from the required net amount, by taking account of loss fractions specified per nutrient type. Next, energy and nutrient concentrations in the biomass of the pasture are calculated for each fertiliser level by linear interpolation between the minimum and maximum production points given earlier, using the total amount of nutrients available for growth. With these concentrations, the soil nutrient balance is again invoked for each fertiliser level, and new amounts of feed on offer are calculated by matching all inputs with all outputs. For example, in case of 0% fertiliser application, the amount of feed on offer cannot be higher than the amount that is produced with external inputs from atmospheric deposition, fixation by micro-organisms, weathering and faeces and urine. In case of 100% fertiliser gift, the amount on offer equals the maximum attainable production. Since PASTOR models grazing-only systems without additional mowing, the amount of biomass eaten by the cattle represents the maximum amount that can be removed. Therefore, the amount of feed actually removed by the cattle is taken as the minimum of cattle intake requirements and the calculated feed on offer. Thus, fertiliser application stops when the target biomass on offer equals the cattle intake requirements, i.e. no 'over-production' is modelled. On the other hand, when fertiliser levels are too low so that cattle intake requirements exceed the amount on offer, it is assumed that the shortage is balanced by feed supplements, thus constituting an additional source of external nutrients to the pasture. Costs and labour requirements are related to material inputs such as fences, tools and herbicides, as well as operations such as establishment, weeding, fertiliser application (if any) and maintenance.

For unfertilised pastures, the calculation procedures are relatively simpler. Since no fertiliser is applied by definition, actual feed on offer is specified by the user as function of a range of feasible stocking rates. In the case of grass-legume mixtures, the soil nutrient balance model takes account of the additional input of N by the legume. The soil nutrient balance is merely the result of bookkeeping of all nutrient inputs and outputs, and may be zero, as for grass-legume mixtures, or negative, as for most *actual* grass-only systems.

Herd

The herd module in PASTOR is able to quantify TCs for breeding and fattening systems, each with a low and a high target growth rate representing *actual* and *alternative* systems, respectively. A breeding system is defined as a system where calves are bred and subsequently sold at a certain age or liveweight. No animals are bought externally. A fattening system is defined as a system where young animals are bought, fattened for a period of time, and then sold. No animals are bred internally. For both types, the modelled herds are 'stationary', which means that there are no dynamics in herd size and composition over the year(s) (Upton, 1989; 1993). Based on a specification of herd structure characteristics, target growth of the animals and target buying/selling strategy, total composition, production and feed requirements of the herd are computed. The (stationary) composition of the herd, i.e. the number and type of animals per age class, is calculated using the method presented by Hengsdijk et al. (1996). The production of the herd is obtained by summing the user-specified target live weight gains and milk production over all animals in the herd, using the user-defined buying/selling strategy. Computations of feed requirements are based on equations as presented by the National Research Council (NRC, 1989, 1996). Calculations were performed for each animal in the herd according to sex and age group, and for females according to stage of pregnancy and lactation, and then added to obtain total herd requirements. Costs and labour requirements of herds are related to construction, buying and maintenance of corrals, feed troughs, various equipment, vaccinations, assistance at birth and animal health care. Costs and labour requirements are quantified for each of these items and operations and summed to obtain herd totals.

Feed

The feed supplement module of PASTOR merely converts data on supplements into feed characteristics (metabolisable energy, crude protein and phosphorus), costs and labour use.

LUCTOR

LUCTOR (Hengsdijk et al., 1998) is able to generate TCs for annual cropping, perennial cropping and timber plantation systems. These systems are characterised through complete operation sequences and include quantification of all inputs and outputs during these sequences (Stomph et al., 1994). For annual cropping systems operation periods are defined (e.g. field preparation, sowing, etc.) in which well defined field operations have to be carried out to take into account the timeliness for operations and to identify labour peaks. For perennial cropping and timber plantation systems no operation periods are identified since in these systems different operations are carried out throughout the entire year and typically occur simultaneously. Therefore, labour requirements for these systems are spread evenly over the entire year in LUCTOR.

Actual and alternative cropping systems are characterised by environmental and management criteria. The most important criteria and their options are shown in Table 3.

Based on user-defined environmental and management options, LUCTOR calculates for each unique land use system its requirements of inputs in physical terms and total costs of input use, as well as associated indicators related to sustainability.

Crop type

In the case of maize and pineapple, two types of crops are defined since their marketable products have a different economic value. In addition, since their growth cycles are distinct input-output relations differ as well. For all other crops included in LUCTOR, one single crop type is defined.

Soil type

Soil characteristics determine which soils are suitable to grow a certain crop, the maximum yield level, suitability for mechanisation (which is a function of stoniness and slope) and nutrient recoveries. Soils may be suitable for a crop only after construction of a drainage system which costs are explicitly taken into account.

Yield level

Ten target yields are defined for alternative land use systems. The maximum target yield level, being the maximum attainable production without nutrient constraints (Bouman et al., 1996), is stepwise reduced with 10% so that the lowest yield is 10% of the maximum attainable production.

Mechanisation level

Mechanisation is largely limited to soil preparation operations in view of the high rainfall intensities in the NAZ combined with soil compaction risk, as well as because of crop characteristics (i.e. narrow passage in perennials).

Crop residue strategy

Crop residues may either be left in the field after harvesting or be harvested and used e.g. for fodder purposes. Both options affect labour requirements and nutrient relationships of cropping systems.

Herbicide and pesticide level

Crop protection agents are divided into herbicides and other pesticides, the latter including fungicides, insecticides and nematicides. In the low herbicide option, herbicides are substituted by manual weeding which requires more labour and reduces the emission of active ingredients to the environment. In the low pesticide option, insecticides and fungicides are reduced with 50% compared to the high pesticide option. It is assumed that with better crop monitoring and hygienic measures, - both of which require additional labour-, the use of insecticides and fungicides can be reduced. This not only reduces emissions of active ingredients but also lowers yields since it is assumed that yield losses occur as a result of lowering pesticide use. The extent of these yield losses is based on expert knowledge.

For quantification of *alternative* cropping systems yield levels are based on the best available field experiments and on discussions with field experts. Furthermore, these systems aim at a closed nutrient balance of N, P and K; this implies that the annual nutrient uptake and losses due to erosion, leaching, volatilisation, denitrification and fixation (only for P) are replenished with nutrients from natural resources (atmospheric deposition, crop residues and fixation by micro-organisms), in addition to a certain amount of fertiliser that is calculated by LUCTOR. The procedure to determine these fertiliser requirements is straightforward and is based on the same bookkeeping procedure as used in PASTOR. The loss fractions per type of nutrient are based on a combination of systems-analytical knowledge and expert judgement. For some perennial and timber plantation systems, nutrient balances may be positive. In these systems account is taken of nutrient turnover during different years of the crop cycle (i.e. the time that the land is planted with a crop). Nutrients in crop residues left in the field after harvesting as well as nutrients in the standing crop are discounted in the following year. At the end of a crop cycle a large flush of nutrients from decomposing crop residues is released, and is available at the start of a crop cycle. In such situations the inputs of nutrients may exceed the sum of the crop uptake and nutrient losses, thus resulting in positive nutrient balances.

Although yield levels of alternative cropping systems are defined at an equidistant range, other outputs and inputs are not; this is justified since higher yield levels are usually associated with higher crop nutrient concentrations (Van Keulen & de Wolf, 1986). In this way non-linear (i.e. diminishing return) relationships are determined between fertiliser requirements and yield levels. Based on de Wit (1994), use of insecticides and fungicides is assumed to decrease proportionally with diminishing yield levels; fungal diseases and insects pests usually require less effort to be controlled under less favourable growing conditions.

It is assumed that inputs in alternative cropping systems are applied in a more technically efficient manner than in actual cropping systems, which is expressed in: (i) crop characteristics that are geared towards higher yields compared to actual systems (i.e.

higher harvest indices); (ii) a shift in the distribution of prime quality fruit towards a higher fraction first quality fruit due to better crop management; (iii) generally higher planting densities, and (iv) higher frequencies of fertiliser applications.

For *actual* cropping systems, the calculation procedures are to a large extent similar to those for alternative systems. However, in the case of actual cropping systems empirical data on yield and use of inputs such as nutrients, labour and crop protection agents are used to determine associated sustainability indicators. Any missing value is estimated using standard agronomic knowledge and expert judgement. The calculation procedure for TCs is the same as used for alternative land use systems. Unlike the approach for alternative systems, where nutrient balances are used as an equilibrium target, nutrient balances of actual cropping systems are a result of loss and gain processes that can be positive or negative. Actual cropping systems do not necessarily have lower yields than alternative cropping systems. However, alternative cropping systems, at least theoretically, can be practised without depleting soil nutrient stocks, while most actual cropping systems are not sustainable in the long run due to their depleting effect on the soil nutrient stock.

USE OF PASTOR AND LUCTOR IN *EX-ANTE* ANALYSIS

PASTOR

The following example shows how PASTOR can be used as a stand-alone tool at the field scale to identify trade-offs among various indicators of land use systems relating to sustainability. This type of analysis supports the design of new land use systems that on the one hand are economically viable while on the other hand meet environmental criteria. PASTOR was used to quantify TCs for fertilised Estrella (*Cynodon nlemfuensis*) on a well-drained, fertile soil type with a stocking rate of three animal units per hectare (Figure 2). Production levels ranged from the minimum to the maximum attainable level on that soil type, by varying fertiliser applications from 0-100% of the amount needed to realise the maximum level. Soil nutrient-balances were closed at all production levels.

In Figure 2a, the trade-off between economic and environmental parameters is illustrated. The horizontal axis gives pasture production, and the vertical axes give the associated use of herbicides and nitrogen loss via denitrification. An increase in pasture production is associated with an increase in denitrification losses, which is clearly an economic-environmental trade-off. However, herbicide use diminishes with increasing production. At higher production levels pastures are more competitive (de Wit, 1994), and thus less herbicides are needed for weed control. Thus, in this example, there exists not only an economic-environmental trade-off, but also a trade-off between environmental parameters: increased yields are associated with increased denitrification losses but with decreased herbicide use. Figure 2b shows that costs of production and labour requirements increase rapidly with increasing production, even though labour requirements grow less rapidly than costs. The explanation for this phenomenon can be found in Figure 2c which shows that both fertiliser requirements and frequency of N-applications increase with higher (target) production levels. Since the use of herbicides decreases at higher production (Figure 2a), and hence the required labour for weeding as well, total labour requirements increase less rapidly than total production costs (Figure 2b).

LUCTOR

This section illustrates the use of LUCTOR as a stand-alone tool for cost-benefit analysis of individual cropping systems by showing how LUCTOR can be used to identify the relative importance of a number of input prices for several cropping systems. This may support priority setting with regard to the implementation of efficiency improvements in cropping systems and as such may be useful for both research and extension efforts.

The effect of a 10% price increase for three inputs (crop protection agents, fertilisers and labour) on total production costs of grain maize, cassava, pineapple for export purposes, banana and palmheart systems is shown in Table 4. Production costs were calculated for alternative cropping systems with a maximum attainable yield level, on fertile well-drained soils, using high levels of mechanisation, herbicides as well as pesticides. Total production calculations were performed using 1996 prices and relative changes in total production costs were compared to this base situation. Costs are discounted costs per ha per year averaged over the length of the crop cycle, which is one year for maize and cassava, 2.2 years for pineapple and 15 years for banana and palmheart. Total production costs include both variable costs and fixed costs required for crop establishment and infrastructure (e.g. drainage, on-farm post-harvest processing unit).

The large differences in average annual discounted costs among cropping systems in the base situation are striking. Production costs of banana and export pineapple are 7 to 12 times higher than those of other crops. This is largely due to post-harvest costs and associated establishment costs for an on-farm processing-unit, as well as costs for drainage and infrastructure in general.

Generally the effects of higher input prices are limited, even though some similarities and differences among inputs and cropping systems are evident. In all cropping systems, with the exception of pineapple, total production costs are most sensitive to changes in fertiliser costs.

Costs of crop protection agents are particular high in banana, pineapple and maize, while much lower in cassava and palmheart. This can be explained by the fact that cassava and palmheart use virtually only herbicides without hardly any other crop protection agent. On the other hand, banana, pineapple and maize require substantial amounts of fungicides, insecticides and/or nematicides.

The sensitivity of total production costs of cassava and palmheart to changes in wages highlights the relative importance of labour in these crops.

CONCLUSION AND DISCUSSION

The presented concept of TCGs to generate TCs for a large number of land use systems integrates systems-analytical knowledge, standard agronomic and animal husbandry data, as well as expert knowledge. Both PASTOR and LUCTOR have been successfully used to systematically generate the necessary input data for various types of land use models used in the NAZ of Costa Rica (Bouman & Nieuwenhuyse, 1998; Bouman et al, 1998a; Sáenz et al., 1998). The development as well as the application of TCs in these land use models has already resulted in fruitful discussions with users about expert-based assumptions. Since both PASTOR and LUCTOR are highly generic and modular, their parameters can easily be adjusted where necessary in order to reflect certain location-specific conditions.

In addition to their traditional role as generators of input data for land use models, PASTOR and LUCTOR are useful tools for decision support as well. For example, both TCGs can be used to quantify trade-offs between socio-economic and sustainability parameters at the field level, or to explore the relative importance of inputs in land use systems through simple cost-benefit analysis. While cost-benefit analysis may support decisions (e.g. with respect to the efficient application of different inputs), trade-offs among different production objectives can be made explicit to identify new options.

Generation of TCs in both PASTOR and LUCTOR is based as much as possible on systems-analytical knowledge of the physical, chemical, physiological and ecological processes involved. For some data and processes, however, the required knowledge is lacking or insufficiently developed to formalise it into process-based models. In such cases, knowledge of experts has been used. Examples include estimates of attainable production in both PASTOR and LUCTOR and the relationships between stocking rate and dry matter use by the cattle in PASTOR. Generic expert systems such as PASTOR and LUCTOR thus stimulate field experts to be explicit about their knowledge, and to make that knowledge transparent and open to critical review and discussion by other experts. The advantage is that such important knowledge is not left unused simply because it can not (yet) be formalised into process-based models. Moreover, there always remains the issue of the balance between expected return from expensive collection of empirical field data and time-consuming development of process-based models, versus the low costs involved with tapping knowledge of field experts. Ignoring expert knowledge leads to less, rather than more reliable information.

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Table 1.

Summary of terminology relating to the quantification of land use systems (adapted from Van Ittersum & Rabbinge, 1997).

Terminology	Description
Land use system	Agricultural land use under specific biophysical and technological condition associated with inputs and outputs.
Alternative land use system	Land use system that represents technically feasible means of production already available or in the R&D pipeline but not (yet) widely applied.
Actual land use system	Land use system that represents the current means of production
Target-oriented approach	Identification of a technically optimal combination of inputs to realise a particular output level
Production level	Level of primary output per unit of area
Production technique	Complete set of inputs to realise a particular output level
Formal knowledge	Standard data, measured data and derived, reproducible calculation rules
Informal knowledge	Subjective expert knowledge
Standard data	Well accepted knowledge and published information

Table 2

Definition criteria and options for pasture systems as implemented in PASTOR for the NAZ of Costa Rica.

Definition criterion	Maximum number of options
Botanical composition	6 (Improved grasses *Cynodon nlemfuensis*, *Brachiaria brizantha*, and *Brachiaria radicans*; grass-legume mixtures *B.brizantha-A.pintoi* and *B.humidicola-A.pintoi* mixture; 'Natural' which represents a mixture of the naturalised and native grasses *Ischaemum ciliare*, *Axonopus compressus* and *Paspalum* spp.)
Soil type	3 (Fertile well drained, fertile poorly drained, infertile well drained[a])
Stocking rate	21 (From 1 to 6 animal units per ha, in steps of 0.25. For the grass-legume mixtures and the natural pasture, stocking rates varied only from 1-3)
Weeding manner	3 (Only herbicides, only manual, mixed herbicides and manual)
Fertiliser application	11 (From 0 to 100% to reach maximum attainable production, in steps of 10%)

[a] Defined as major soil units in the NAZ (Hengsdijk et al., 1998).

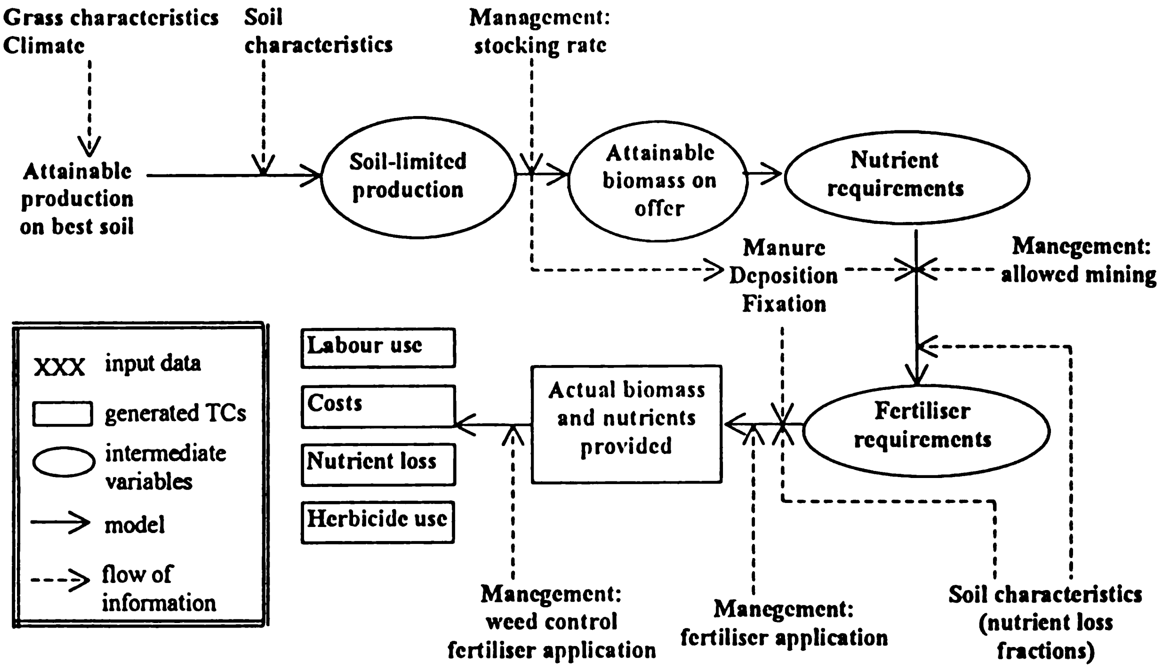

Figure 1

Schematic representation of calculation procedure of TCs by PASTOR for fertilised, *alternative* pastures.

Table 3

Definition criteria and options for cropping systems as implemented in LUCTOR for the Northern Atlantic zone of Costa Rica

Definition criterion	Maximum number of options
1. Crop type	11 (Bean, cassava, maize-grain, maize cobs, pineapple-export, pineapple-local, banana, plantain, palmheart, teak and melina)
2. Soil type	3 (Fertile poorly drained, fertile well drained, infertile well drained)[a]
3. Yield level	11 (10 Target yields for alternative systems, 1 yield level for actual systems)
4. Mechanisation level	2 (Low and high)
5. Crop residue strategy	2 (Harvesting, left at field)
6. Herbicide level	2 (Low and high)
7. Pesticide level	2 (Low and high)

[a] Defined as major soil units in the NAZ (Hengsdijk et al., 1998).

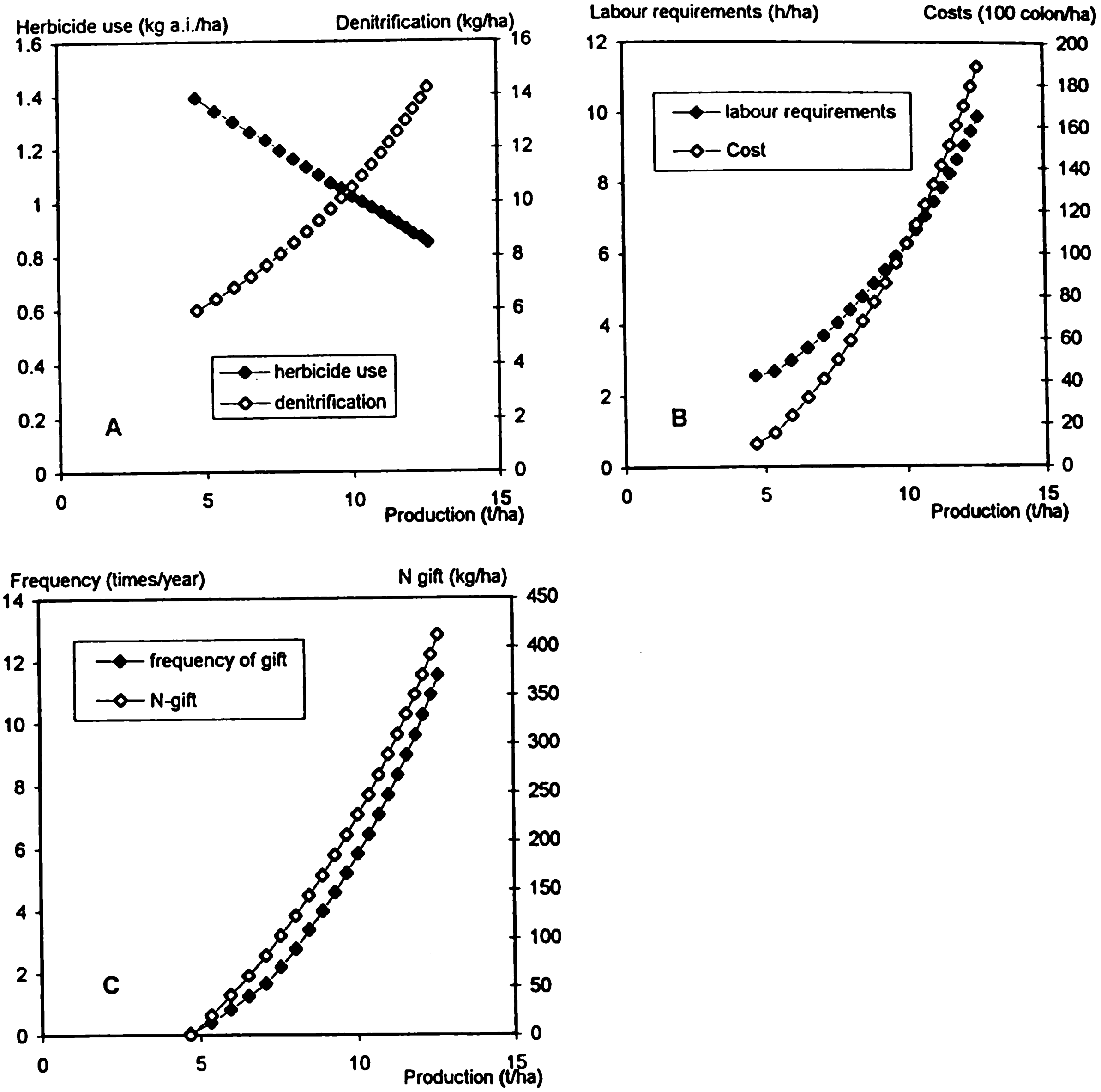
Herbicide use (kg a.i./ha)
Denitrification (kg/ha)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
16
14
12
10
8
6
4
2
0
herbicide use
denitrification
A
0
5
10
15
Production (t/ha)
Labour requirements (h/ha)
Costs (100 colon/ha)
12
10
8
6
4
2
0
200
180
160
140
120
100
80
60
40
20
0
labour requirements
Cost
B
0
5
10
15
Production (t/ha)
Frequency (times/year)
N gift (kg/ha)
14
12
10
8
6
4
2
0
450
400
350
300
250
200
150
100
50
0
frequency of gift
N-gift
C
0
5
10
15
Production (t/ha)

Figure 2

Generated TCs by PASTOR for fertilised *Cynodon nlemfuensis* on a well-drained, fertile soil with a stocking rate of three animal units per hectare. Figure 2a shows relationships among production, herbicide use and denitrification; 2b among production, labour requirements and costs of production, and 2c among production, frequency of fertiliser and N applied. All data are annual values.

Table 4

Relative change in total production costs of five alternative cropping systems compared to the base situation (average prices in 1996 colones) for a 10% increase in the price of crop protection agents, fertilisers and labour, respectively (207.38 col = 1 US$).

Crop	Base situation (colones)	+10% Price crop protection agents (% change)	+10 % Price fertilisers (% change)	+10% Price labour (% change)
Cassava	328.965	0.3	3.3	3.2
Grain-maize	291.661	1.6	3.1	1.5
Banana	2.530.783	1.8	1.8	1.2
Palmheart	201.652	0.2	4.4	3.4
Export-pineapple	2.429.993	1.5	0.8	0.8