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A static, descriptive approach to quantify land use systems

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Abstract

Quantitative tools for analysis and planning of land use require descriptions of land use systems, for example to use in optimisation models. A static, descriptive formulation of land use systems, called Land Use Systems at a defined Technology (LUSTs), is discussed, that describes quantified operation sequences. Attributes, such as prices and nutrient contents, do not form part of these LUSTs, but are described separately, thus allowing for separation of technical options from socioeconomic limitations. Examples are given for the Atlantic Zone of Costa Rica. Advantages of and limitations to the LUST approach are discussed.

Keywords: Costa Rica, land use systems, operation sequence, quantitative land use analysis

Introduction

Considerable efforts are being spent on developing tools for analysis and planning of land use, e.g. Fresco *et al.* (1994). Qualitative (Anonymous, 1983), or semi-qualitative (Hackett, 1988) methods can indicate the suitability of a certain land use type (LUT) for a certain land unit (LU). These, however, do not facilitate selection of the 'best' combination of land use systems in a given situation, nor can they indicate effect of specific technologies on the sustainability of the land use. Better geared for that task are methods that quantify input-output relations (Driessen, 1986; Van Diepen *et al.*, 1991; Stomph *et al.*, 1994), thereby facilitating optimisation of land use in relation to one or more goals, such as maximising net economic benefit, and to one or more constraints, such as availability of labour and land, or limits to the use of natural resources (e.g. Spharim *et al.*, 1992; Veeneklaas *et al.*, 1990; Stroosnijder & Van Rheenen, 1993; Alcocilja & Ritchie, 1993; Fuchs & Murschel, 1992). As has been argued by the Dutch Scientific Council for Government Policies (Anonymous, 1994b), sustainability is a subjective concept, related to present day knowledge, morals, interests, etc. This implies that criteria for indicating sustainability of land use (e.g. nutrient balances, as used by Ehui & Spencer, 1993; Solórzano *et al.*, 1991) can change over time. Without doubt, the knowledge about land use systems is continuously changing, and with it, the quantification of at least part of the coefficients that characterise land use systems, such as nitrate leaching and phosphate accumulation (e.g. Spiertz *et al.*, 1994), or erosion. The relativeness of the coefficients and their quantification, makes that a description of land use systems with the help of specific coefficients limits the relevance of these descriptions to particular applications. Instead, land use systems can better be described in terms of operation sequences (i.e. listing all management operations) that include a quantification of all inputs and outputs (Stomph *et al.*, 1994). Such a description serves then as basis for the calculation of the required coefficients. This has the advantage, that land use systems do not have to be described again for each change in the calculation of the coefficients.

The quantification of inputs and outputs can be done in a dynamic, explanatory way, by explicitly formulating relations between inputs and outputs and the effect of environmental conditions (Stomph *et al.*, 1994). A major advantage of such a dynamic, explanatory formulation is its portability, i.e, it can be used in many different situations, without having to change the description itself. Also, the optimal combination of management practices for a given farm could be found with such a dynamic, explanatory approach, given the goals and the constraints imposed by the bio-physical and socioeconomic environment. This dynamic approach, however, needs comprehensive crop or farm management models that at present do not exist (e.g. Dent, 1993). Although some models can accurately calculate production of specific crops under potential production situations (Herrera-Reyes & Penning de Vries, 1989; Kropff *et al.*, 1993), models for other production levels often do not produce accurate results (e.g. Angus *et al.*, 1993). Exact management procedures and quantities of inputs required are at present generally not an output of these simulation models, and can at best be 'guestimated'. Large amounts of data are required for the construction and parameterisation of these models, as well as for the description of the environment. At present, lack of data is hampering the development of dynamic formulations of land use systems. In developing countries it constrains the use of relatively simple crop models (Anonymous, 1994a), even though serious efforts are undertaken to train local researchers in systems research, including experimentation to obtain the required data (Ten Berge, 1993; Uehara & Tsuji, 1993). The development of dynamic formulations of land use systems is therefore a long term process, especially in developing countries. Meanwhile, a more pragmatic approach to describe land use systems has to be followed.

This article discusses the static, descriptive approach followed by the Atlantic Zone Programme (AZP) in Costa Rica, as part of its methodology denominated *Uso Sostenible de Tierras En el Desarollo* (USTED: Sustainable Land Use in Development), a tool for quantitative analysis of land use (Stoorvogel *et al.*, 1995).

Material and Methods

Concepts

Methods for describing land use have been a point of discussion for quite some time. The FAO (Anonymus, 1976) has come up with a set of guidelines on what aspects to include, and how to differentiate various aspects of land use, among others separating Land Unit (LU) from Land Use Type (LUT). The original definition states that LUTs 'are described with as much detail and precision as the purpose requires'. As such, the term Land Use System (LUS), being the combination of LU and LUT, can be used to for any description of land use on LU level. Here, the term 'Land Use System at a defined Technology' (LUST) is proposed for a specific form of describing land use that includes a quantification of the technology. Each LUST is described in an individual database, including an identification section, indicating the unique combination of LU and LUT. The body of each LUST description is formed by a chronological and quantitative description of a particular operation sequence, that comprises at least one full crop cycle, and might contain rotations (i.e. a LUT with more than one crop). While the LUSTs descriptions quantify all inputs and outputs, data common to a variety of LUSTs can be stored separately, to minimise duplication, and to facilitate maintenance of the databases. Also, the LUST descriptions do not necessarily contain all the information needed for analysis of the LUSTs. This information, e.g. prices, nutrient contents, toxicity, is stored separately from the LUST descriptions in so-called attribute databases. Users of LUST descriptions need to develop customised procedures to extract information from the LUST descriptions and the attribute databases, and to convert this information into coefficients for further analysis. To enable referencing between the various databases, a clear definition of the data is required, while unique identifiers should enable recognition of similar data in different databases.

Structure of LUSTs in USTED

In USTED, LUST descriptions are used in the calculation of technical coefficients for different options of land use. These coefficients form the basis for a linear programming (LP) model to calculate the optimal combination of LUSTs on farm and regional level, for a given set of goals and constraints that describe the biophysical and socioeconomic environment (Schipper *et al.*, 1995). Changes in the description of the environment can lead to changes in the calculation of the technical coefficients. Automation of data flows to the LP model is via the customised software MODUS (MOdules for Datamanagement in USTED; Stoorvogel *et al.*, 1995), requiring a specific structure of the LUST description (see below). The FAO FARMAP coding system (Anonymous, 1986) is used to generate unique identifiers for the various entries in the different databases.

In the LUSTs for USTED, each operation is described by a quantity of biophysical inputs or outputs, split into four groups: labour, traction, equipment and materials. A distinction is made between 'traction' and 'equipment', where the former comprises machines that provide power to equipment. 'Equipment' relates to tools that do not generate power, and that can be used by themselves (e.g. machete), or in combination with traction (e.g. disc plow). The group 'materials' comprises goods that are consumed during use (e.g. biocides).

At present, nine types of operations are considered (Table 1), including the group 'animal related operations'. In future versions of MODUS, the latter will be subdivided, but this was considered not necessary for the rather simple, extensive, pasture systems that occur in the Atlantic Zone.

Different types of operations often use different types of materials. In MODUS, therefore, access to specific attribute databases (Table 1) is made dependent on the type of operation. This facilitates creation of new LUSTs, since per operation only a limited set of 'materials' has to be considered to obtain the required code. For most operations, 'materials' are inputs, however, for the operation 'harvesting' they have been defined as output, i.e. the harvested product.

Describing LUSTs

Actual land use is determined by current conditions, such as prices for inputs and outputs, knowledge of alternatives, availability of credit, etc. Often, it does not suffice to describe only the actually occurring LUSTs. Instead, alternatives should be identified and described as well. Various sources of information exist, on which to base the description of both actual and alternative LUSTs: enquiries among farmers, observations in farmer's fields, results from experiments in the region of interest, literature data referring to other regions, LUSTs occurring in other regions, and expert knowledge, including simulation models. Often a mixture of sources has to be used to obtain a complete description of a LUST. It should be stressed, that the reasoning behind the relation of outputs to the inputs is not part of the LUST, and that each LUST should be based on an analysis of this relation in the given situation.

In theory, an infinite number of LUSTs can be created, to account for differences in LUs, LUTs and technologies. In practice, however, limits are imposed to the number of LUSTs that can be handled by the users, among others due to restrictions of the tools for analysis of LUSTs. Decisions on how to limit the number of LUSTs are affected by the level of land use analysis or planning: e.g. on farm level, all occurring LUs could be taken into consideration, whereas on regional level it is often needed to aggregate different LUs.

Restricting the number of LUTs is often also required, especially for tropical regions where a large number of crops, and for each crop a large number of varieties, can be grown. Selection of LUTs can be made on basis of historical, actual or potential importance, and on availability of information.

Many alternative technologies exist to execute each field operation: by using different types of traction, equipment and materials, by applying different amounts of labour and materials, and by changing the timing of the operation. It is undoable to describe all possible combinations, and here it is suggested to focus on the descrip-

Table 1. Contents of the attribute databases and the type of operations to which they are available in MODUS (see text)[1]

Database	Attributes	Operations
LABOUR	price, unit	
EQUIPMENT	price, unit, labour use[4]	all
TRACTION	price, unit, labour use[4]	all
ANIMAL_BREED	price, unit	Animal related operations
ANIMAL_PRODUCT	price, unit	Animal related operations
BIOCIDES	price, form, amount, unit fraction A.I.[2], WHO-code for toxicity, duration of action in system (days), solubility in water (mg/l), common name	Weeding (manual, mechanical & chemical) Biocide application (other than herbicides)
CROP_PRODUCT	price, unit, amount (kg fresh weight per unit), %DM, %N, %P, %K, %HI[3], %SumNMx[3], %SymNMn[3], code of residue in CROP_RESIDUE, coded name	Harvesting
CROP_RESIDUE	%N, %P, %K	
CROP_SEED	price, unit, amount	Seed(ling) manipulations
FERTILISER	price, unit, amount, fraction N, P and K	Fertiliser application
MATERIALS	price, unit, amount	Land/field preparation Post-harvest operations Other field operations
LANDUNIT	pH, % OM, % clay, slope	
OPERATIONS	types of operations	all
UNIT	units of measurement	all

[1] Omitted are attributes 'code' and 'name', that appear in each database, where 'name' refers to the local or commercial name. LABOUR is used directly by the optimisation model, CROP_RESIDUE and LANDUNIT are used by the data management module in USTED (Stoorvogel *et al.*, 1995).
[2] Fraction Active Ingredient, WHO code, duration and solubility can be specified for up to two active ingredients per commercial product
[3] Harvest Index (in %) and maximum and minimum symbiotic N as percentage of total N in the plant
[4] To indicate whether labour is included or not in the price, to enable inclusion of contract labour

tion of alternatives that have different use of the major constraining production factors in the area of work, and/or on the factors that are analysed in the study for which LUSTs are described.

Several of the theoretically feasible combinations of LU, LUT and technology can be excluded. High applications of inputs in general do not occur on poorly-drained LUs, unless a drainage system is constructed (which should be included in the LUST descriptions). Similarly, high applications of pesticides will not take place on infertile LUs when no fertiliser is applied.

The study area

The Atlantic Zone in the North-East of Costa Rica has a tropical climate, with an annual rainfall of 3500–4400 mm, and an annual rainfall surplus of between 1350 and 2550 mm, depending upon location within the Zone. Even the dryest period (February to April) generally has a rainfall surplus. The Neguev settlement in the Zone is chosen for development and testing of the USTED methodology. The Neguev comprises 307 farms, with an average farm size of 13.8 ha. More details are given by Stoorvogel *et al.* (1995) and Schipper *et al.* (1995).

Results

For the Atlantic Zone Programme, with its emphasis on the analysis of land use at the regional level, the original twenty odd soil types that occur in the sub-region for which the optimisation model was run (see Schipper *et al.*, 1995), have been grouped into three major LUs, reflecting the major factors that affect productivity of the LUs in the Atlantic Zone: fertile, well-drained, fertile, poorly-drained and infertile, well-drained LUs (for details, see Stoorvogel *et al.* 1995). Differences within each group, e.g. in soil fertility, are assumed to be minor in comparison to differences between the groups, and to be negligible when related to the uncertainties of other assumptions (such as the value of efficiency of fertiliser application).

The following LUTs were selected on basis of their historic, actual or possible importance: cassava, maize, palm-heart, pineapple, plantain, natural forests, tree plantations and beef-cattle production systems.

In the Atlantic Zone, major imputs in land use are labour and fertilisers, whereas in the land use analysis study using the LP model, also biocide use is considered. Differences in the various LUSTs developed for the AZP are therefore mainly in the use of these factors.

As example, two LUSTs from the AZP are presented, both for maize. Tables 2 and 3 contain the encrypted descriptions for an actually occurring and an alternative LUST, respectively, both for a fertile well drained LU. The actual LUST is based on information obtained in weekly interviews of farm households in the Neguev and the neighboring Río Jiménez areas. In these interviews, each farm household was asked to indicate the type of operations used in its current land use activities, of the labour and other inputs used, and of the outputs achieved. In the 1991–1993 period, twelve farms were followed during one year, and eight farms between one and a half and two years.

The alternative LUST is based on a combination of sources, comprising results from experiments, expert knowledge and judgement, and literature, including information that is used by the *Banco Nacional de Costa Rica* (BNCR) in the evaluation of credit applications. The yield of the alternative LUST is estimated with the crop simulation model MACROS (Penning de Vries *et al.*, 1989), as the average potential yield over a period of 10 year for two sites in the Atlantic Zone. Potential yield refers

Table 2. Example of actual maize LUST, sown 15 January on a fertile well drained soil, typical for the Neguev area of the Atlantic Zone of Costa Rica. Traction is not used, and therefore not indicated, while the identification section is omitted. See text for explanation.

Line nr	Operation code	Date	Labour hours	Equipment code	Material			Description
					amount	code	unit	
1	1.0200	311291	20	8800	0	0.000	0	landprepartion
2	3.0350	20192	10	7330	2	1600.208	3	herbicide appl
3	2.0210	150192	10	8200	20	40.000	1	sowing
4	4.0450	300192	10	0	50	1220.000	1	fertiliser appl
5	4.0450	300192	0	0	5	1542.000	1	fertiliser appl
6	6.0310	300192	40	0	0	0.000	0	guarding field
7	3.0350	310192	10	7330	2	1600.208	3	herbicide appl
8	4.0450	20392	10	0	50	1220.000	1	fertiliser appl
9	4.0450	20392	0	0	5	1542.000	1	fertiliser appl
10	3.0350	20392	10	7330	2	1600.208	3	herbicide appl
11	6.0310	210392	35	0	0	0.000	0	guarding field
12	3.0350	10492	10	7330	2	1600.208	3	herbicide appl
13	7.0610	100492	5	0	300	11.000	11	harvesting
14	6.0471	150492	15	0	0	0.000	0	doblar
15	7.0610	150592	50	0	100	12.000	11	harvesting

to the production without water or nutrient stress, and in absence of yield reduction by weeds, pests or diseases (conform De Wit & Penning de Vries, 1982). Effect of water shortage or excess are unlikely to occur in view of the high rainfall, the high hydraulic conductivity of the well drained LUs, and the absence of a shallow soil water table in these LUs. Requirements for fertiliser and other inputs needed to achieve this potential yield, are estimated, see below. No data are available for a local variety, and simulations are done with parameters for a tropical maize variety from Malaysia (Wan Sulaiman & Rushidah, 1991). This variety is grown in a region that has similar temperatures and day lengths to the Atlantic Zone, and it is assumed that its behavior is similar to varieties presently used in the Atlantic Zone.

In both LUSTs, no tillage takes place, and no mechanisation is used, due to the low workability of the soil. Broadcast application of fertilisers is done by hand, while knapsack sprayers are used in biocide applications (code 7330 in the equipment column). Planting sticks (code 8200) are used for sowing and machetes (code 8800) are used for hand weeding and for land preparation (that mainly consists of removal of weeds).

Each operation is timed on a particular date.

The two LUSTs differ in the following aspects:

1. Sowing (line 3 in Tables 2 and 3): the actual LUST is sown in January, compared to the July sowing date of the alternative LUST, reflecting the two major periods for sowing maize in the Atlantic Zone. Less time is spend on sowing in the actual LUST compared to the alternative LUST: 10 versus 25 hours (the latter from BN-

Table 3. Example of alternative maize LUST, sown 15 August on a fertile well drained soil, where potential production is achieved at high input levels. Traction is not used, and therefore not indicated, while the identification section is omitted. See text for explanation.

Line nr	Operation code	Date	Labour hours	Equipment code	Material			Description
					amount	code	unit	
1	1.0200	200692	50	8800	0	0.000	0	landpreparation
2	3.0351	50792	10	7330	2	1600.208	3	herbicide appl
3	2.0220	150792	25	8200	19	41.000	1	sowing
4	5.0352	150792	10	7330	5	1620.303	1	insectide appl
5	3.0351	170792	10	7330	2	1600.208	3	herbicide appl
6	6.9100	200792	1	0	0	0.000	0	checking field
7	6.9100	250792	1	0	0	0.000	0	checking field
8	4.0450	250792	10	0	82	1220.000	1	fertiliser appl
9	4.0450	250792	1	0	128	1320.000	1	fertiliser appl
10	3.0351	40892	10	7330	2	1601.201	3	herbicide appl
11	6.9100	40892	1	0	0	0.000	0	checking field
12	6.9100	140892	1	0	0	0.000	0	checking field
13	5.0352	140892	10	7330	1	1620.401	3	insectide appl
14	3.0420	190892	20	8800	0	0.000	0	weeding
15	4.0450	190892	10	0	82	1220.000	1	fertiliser appl
16	4.0450	190892	1	0	128	1320.000	1	fertiliser appl
17	6.9100	30992	1	0	0	0.000	0	checking field
18	3.0420	80992	20	8800	0	0.000	0	weeding
19	4.0450	80992	10	0	82	1220.000	1	fertiliser appl
20	6.9100	230992	1	0	0	0.000	0	checking field
21	4.0450	280992	10	0	82	1220.000	1	fertiliser appl
22	5.0352	300992	10	7330	1	1623.004	3	insectide appl
23	5.0352	101092	10	7330	2	1619.902	1	fungicide appl
24	6.9100	131092	1	0	0	0.000	0	checking field
25	6.0311	231092	55	0	0	0.000	0	chasing birds
26	6.0600	21192	1	0	0	0.000	0	asses maturity
27	6.0600	121192	1	0	0	0.000	0	asses maturity
28	7.0610	121192	200	0	13.7	13.000	13	harvesting

CR). Especially the former seems low compared to the 20–50 hours mentioned for the Atlantic Zone (Anonymous, 1985; Brink, 1988), or the 80 hours ha^{-1} mentioned by Van Heemst (1986), and might reflect a more careless form of sowing. Seed is used at 20 kg per ha, with a local variety (code 40.000) and a high yielding variety (code 41.000) in the actual and alternative LUST, respectively. These varieties have different prices in the CROPSEED database: 62.50 versus 135.00 *colones* per kg (1 US $ equivalent to about 122 *colones* in 1991). The resulting plant density in the alternative LUST is higher, due to smaller distances between and within the rows (0.2 * 0.5 m versus 0.6 * 1 m), which is possible because of a smaller number of seeds per plant-hole (1 versus 3), made feasible due to a higher germination percentage.

2. Land preparation (line 1 in Tables 2 and 3): considerable more time is spent in the alternative LUST (data from BNCR) on cleaning the land than in the actual LUST:

50 versus 20 hours ha^{-1}. Other observations on farmers fields indicate around 15–20 (Brink, 1988), and 60 hours ha^{-1} (Anonymous, 1985).

3. Weeding: in both LUSTs, a first application of paraquat (code 1600.208) at 2 l ha^{-1} is given soon after land preparation (line 2 in Tables 2 and 3). To assure high productivity in the alternative LUST, four additional weeding operations take place, with paraquat at two Days After Sowing (DAS, Table 3, line 5), with Atrazine (code 1601.201, line 10) at 20 DAS and two hand-weedings at 35 and 55 DAS (lines 14 and 18). In the actual LUST, paraquat is applied at 16, 66 and 96 DAS (Table 2, lines 7, 10 and 12). Labour for spraying herbicides is set at 10 hours ha^{-1} (conform BNCR) in both LUSTs. Labour requirements in literature of 25 (Van Heemst, 1986), and 18 hours ha^{-1} (Anonymous, 1985), might reflect a more careful application, which is needed when the crop is well established. This does not apply for the alternative LUST, where herbicides are used only in the early stages of the crop, but might indicate a cause for yield loss in the actual LUST due to spoiling herbicide on the crop, especially in the later applications. The large interval between the successive herbicide applications in that LUST can result in a strong competition especially with the grass weeds that grow fast in the wet, humid climate of the Atlantic Zone.

4. Fertilisation: in the actual LUST a total of 100 kg ammonium nitrate (code 1220.000) and 10 kg 12–24–12 (code 1542.000) is given in two splits (Table 2, lines 4 and 9). In the alternative LUST, the required application is dependent on yield, according to Equations 1–3 (no compound fertilisers are used), with parameter estimates as in Table 4.

$$A_j = (U_i - S_i)/(E_{ij} * F_{ij}) \quad (1)$$

$$U_i = P * fP_i + R * fR_i \quad (2)$$

$$R = P * (1/HI - 1) \quad (3)$$

where:
A_j = required total application of fertiliser j (kg ha^{-1})
U_i = total uptake of nutrient i (kg ha^{-1})
S_i = uptake of nutrient i from the soil (kg ha^{-1})
E_{ij} = efficiency of application for nutrient i in fertiliser j
F_{ij} = fraction of nutrient i in fertiliser j
P = amount of dry matter in product (kg ha^{-1}) = $P_w*(1-fP_w)$
P_w = amount of fresh product (kg ha^{-1})
fP_w = fraction water in fresh product
fP_i = fraction of nutrient i in product
R = amount of dry matter in residue (kg ha^{-1})
fR_i = fraction of nutrient i in residue
HI = harvest index = $P/(P+R)$

Table 4. Parameter used in the calculation of nutrient application (see text for abbreviations).

Parameter	unit	N	P	K	Weight
S_i[1]	[kg ha^{-1}]	82.	20.	122.	–
E_i[2]		0.72	0.133	0.60	–
F_i[2]	[kg kg^{-1}]	0.335	0.20	0.386	–
f_i[3,4]	[kg kg^{-1}]	1.28	0.23	0.59	–
fR_i[4]	[kg kg^{-1}]	0.66	0.08	1.16	–
P_w	[kg ha^{-1}]	–	–	–	13700
fP_w	[kg kg^{-1}]	–	–	–	0.25
P	[kg ha^{-1}]	–	–	–	10960
HI	[kg kg^{-1}]	–	–	–	0.70
R	[kg ha^{-1}]	–	–	–	4700
U_i	[kg ha^{-1}]	160.	27.	112.	–
A_i[2]	[kg ha^{-1}]	327.	257.	0.	–

[1] maximum delivery for nutrient *i* by the soil, when other nutrients are available in sufficient amounts. Based on fertiliser experiments by Chin (unpublished).
[2] for ammonium nitrate, triple superphospate and KCl, respectively.
[3] on a dry matter base, product composition of 70% grains and 30% cob and cover.
[4] based on Van Duivenbooden (1992).

In view of the large amount of K that can be taken up from the soil, no fertiliser K is given. N is applied as ammonium nitrate in four splits, and P as triple super phosphate (code 1320.000) in two splits (Table 3, lines 8, 9, 15, 16, 19 and 21). This application scheme results in a higher efficiency of application (0.72 and 0.133 for N and P, respectively) than found in a fertiliser trial by Chin (unpublished results: 0.5 and 0.02), who applied N in two splits and P in one dressing. Both LUSTs use similar amounts of labour per fertiliser application (10 hours, BNCR), whereas in the alternative LUST one additional hour is required for mixing of the two types of fertiliser that are applied together. These figures are well within the range (3–18 hours ha^{-1}) found by others (Van Heemst, 1986; Brink, 1988 and Anonymous 1985).

5. Crop protection and maintenance: in the actual LUST, two types of protection operations take place, 'guarding of the crop' (Table 2, lines 6 and 11), and '*doblar*' (line 14), where the maize plants are bent such that the cobs hang upside down. This practice reduces bird damage and limits infiltration of rain water in the comb, thereby preventing growth of fungi that otherwise could result in yield losses of up to 25% (Monge, 1989). The '*doblar*' operation (at 15 hours ha^{-1}) is done during the grain filling phase, thereby probably affecting the final weight of the grains and cobs. No measures are taken against insects, although spraying with insecticides is advised, among others against *Spodoptera frugiperda*, *Phyllophaga spec.* and *Diabrotica spec.* (Monge, 1989; Anonymous, 1985). In the alternative LUST, three insecticide applications take place: with carbofuran at sowing (code 1620.303, Table 3, line 4), with trichlorfon at 30 DAS (code 1620.401, line 13), and with methamidophos at 77 DAS (code 1623.004, line 22). To avoid yield loss

due to fungi, triadimefon is sprayed at 87 DAS (code 1619.902, line 23). Regular checking of the field (lines 6,7,11,12,17,20 and 24) is done to ensure that the protection operations are done in time. During the grain filling phase, an additional 55 hours ha^{-1} (Van Heemst, 1986) has to be spent on chasing birds (line 25). To ensure a correct timing of the harvest, in the alternative LUST two times one hour is spend on assessing crop maturity (Table 3, lines 26 and 27).

6. Harvesting: in the actual LUST, both fresh young cobs (code 11.000, Table 2, line 13) and mature cobs (code 12.000, line 15) are harvested, in quantities of 300 pieces ha^{-1} and 100 bags of 40 kg ha^{-1} respectively. In the alternative LUST, only mature cobs (25% humidity) are harvested (code 13.000, Table 3, line 28), at 13.7 ton ha^{-1}. Although mature cobs are harvested in both LUSTs, they have a different code, and a different price per unit of measurement, since in the actual LUST they are sold in bags, while as bulk in the alternative LUST. Labour requirements for manual harvesting are 200 hours ha^{-1} for the alternative LUST, versus 50+5 hours ha^{-1} for the actual LUST. However, per ton dry cobs, labour use is less in the latter: 12.5 versus 14.6 hours for the alternative LUST. These figures are in line with the 13.9–20.4 hours ton^{-1} mentioned by Brink (1988) for yield levels of 2.8–5 ton ha^{-1}, but much lower than the 90 and 48 hours ton^{-1} for yield levels of 1 and 2.5 tons ha^{-1} respectively (Anonymous, 1985). The 110 hours ton^{-1} of Van Heemst (1986) seem rather too high compared to these figures, but might refer to grains instead of cobs.

Other alternative maize LUSTs are based on the presented LUST with potential production, by replacing herbicide spraying by hand weeding operations (assuming similar efficiencies in weed removal), including '*doblar*' instead of 'chasing birds' (and assuming a 15 % yield loss due to inadequate filling of grains), lowering the fertiliser applications (with varying yield reductions), and omitting checking of the field and zero application of insecticides and fungicide (assuming a 20% yield reduction). With a constant labour requirement per ton product, the different combinations of management practices give differences in yield levels, economic costs and benefits and labour demands (Table 5). Maize does not grow well on the infertile, well-drained LU, among others due to problems with germination (Chin, unpublished results). On fertile, poorly-drained LUs flooding occurs often and excess of water strongly limits growth of maize. For these LUs no maize LUSTs were described.

For the fertile, well-drained LU, similar LUSTs as for maize were constructed for cassava, palm-heart, pineapple and plantain, and with exception of the latter, also for the infertile, well-drained LUs. For the latter, the amounts of N, P and K that can be delivered by the soil (S_i in Equation 1) are 35, 34 and 73 % respectively of what can be taken up from the fertile well drained LUs (based on fertiliser trials by Chin, unpublished). Maximum yearly uptake from the soil for perennials (including cassava) is assumed to be 1.5 times the maximum uptake by maize (S_i in Table 4). For both LUs similar efficiencies of fertiliser application are used, assumed to be related more to management (frequency and timing) than to LU. For a given potential production levels of each LUT (estimated on basis of literature data), required fertiliser

Table 5. Characteristics of the different maize LUSTs (see text)

LUST	Weed	Doblar	Check	Bioc	Fert	Yield	Gross	Costs	Added	Labour
Actual	C[1]	Y[2]	N[2]	N[2]	?[3]	?[4]	56083[5]	9437[6]	46646[7]	235[8]
Alt 40	C	N	Y	Y	100	100	188882	83235	105647	491
Alt 41	M	N	Y	Y	100	100	188882	79659	109223	541
Alt 42	C	Y	Y	Y	100	85	159281	83235	76046	426
Alt 43	M	Y	Y	Y	100	85	159281	79659	79622	476
Alt 44	C	Y	Y	Y	50	74	139547	74989	64558	404
Alt 45	M	Y	Y	Y	50	74	139547	71413	68134	454
Alt 46	C	Y	N	Y	0	63	118403	66744	51660	333
Alt 47	M	Y	N	Y	0	63	118403	63168	55236	383
Alt 48	C	Y	N	N	0	50	94441	6518	87923	268
Alt 49	M	Y	N	N	0	50	94441	2942	91499	318

[1] Manual only or also Chemical weeding
[2] Yes or No *'doblar'* instead of bird chasing, checking of field, and application of insecticide and fungicide.
[3] application of fertilisers in percentage of total needed for potential production
[4] yield level in percentage of potential
[5] total gross income from selling of products (*colones* ha^{-1})
[6] total costs of inputs (excluding labour; *colones* ha^{-1})
[7] total value added (= gross income - costs; *colones* ha^{-1})
[8] total labour used per crop cycle (hours ha^{-1})

application rates can be calculated according to Equations 1–3, using LUT specific parameters for nutrient percentages, harvest index and dry matter content (assumed to be not influenced by LU).

Various LUSTs, for all three LUs, were made for natural forests and tree plantations (Van Leeuwen, unpublished), on the basis of observations on farmers fields, interpretation of literature, and a model to calculate growth and production of trees (Poels, 1994). Per LU, including the fertile poorly drained LUs, two simple beef-cattle production systems were described, based upon farmers practices.

Discussion

The LUST concept, as worked out by the AZP, forms a simple and flexible approach to describe land use systems on a land unit level. Socioeconomic aspects of land use are separated from the LUST description, and are stored in attribute data bases (such as prices that might differ between regions) or appear as part of the goals and constraints of the optimisation model. The separation of technical options from socioeconomic conditions allows for calculation of optimal land use under various technology options and different socioeconomic conditions. Thus, effects on land use can be studied e.g. as influenced by changes in prices, or in labour availability. Examples of use of LUSTs in such analysis are given by Schipper *et al.* (1995) and Jansen *et al.* (1995).

LUST and attribute databases are straightforward and easy to update (i.e. including improved information on already described operations or attributes) and to upgrade (i.e. including additional operations or attributes). The LUST database setup can also be used to describe production systems that do not use land. This is the case with household activities, such as cooking and child care. Also, animal production systems at a defined technology (APSTs) can be described such that they make use of products of LUSTs (grass, crop residues), without having to specify again the land requirements of these LUSTs. Databases of these activities can be quantified in a similar structure as the LUSTs, facilitating an integrated analysis of farm households.

To enable comparison of different LUSTs, each LUST should be described completely, i.e., with all the required operations. When a certain technology requires a capital investment, e.g. for the construction of a drainage system, the corresponding LUST should incorporate the entire period of depreciation of the investment. Land reclamation operations which are required by most LUSTs, e.g. operations to convert forest into arable land, need not to be included in each individual LUST description, but instead can be described separately.

Our LUST approach does not allow for the direct description of complex management practices that are a combination of two or more types of operations. This is the case, for example, when insecticides are applied during sowing. However, such combined practices can be separated into two (or more) 'simple' operations, e.g. by splitting the concurrent application of two types of fertiliser in mixing and broadcasting on the field (Table 3, lines 8,9). Complex land use systems, e.g. intercropping systems, can similarly be broken down into simple operations. The LUST setup allows for inclusion of more than one LUT, as long as all LUTs fall on the same LU.

At the farm and regional levels, interactions can exist between different land use systems, either visible or invisible. Visible interactions are those that require specific operations in either or both the interacting land use systems, e.g. crop-livestock interaction where manure is applied to crops. The LUST approach allows for the description and quantification of all the inputs and outputs of these operations. When LUST descriptions are used in an analysis of land use at higher levels than the LU (e.g. farm level), care should be taken to balance inputs and outputs of the visible interactions. Thus, it should be ensured that not more manure is be used than is produced or imported from other regions. Invisible interactions take place, even in the absence of specific 'interaction' operations. This is the case, e.g. with the carrying over of enhanced soil fertility due to fallowing or growing leguminous crops, or with the reduction in soil born pests and diseases in crop rotations. These invisible interactions, with either a spatial or a time related dimension, can only be incorporated by describing the whole complex of interacting land use systems into one particular LUST. Although these systems can be complex in structure, they can be described with the same type of operations as more simple cropping systems.

In the present LUSTs, per harvest only one figure is given to indicate the production level. In general this should be a long term average (either actually measured or calculated with simulation models). To indicate the spread around this average, the standard error could be included in the LUST. Thus, analysis of (part of) the risks involved with each LUST could be calculated.

The static, descriptive LUSTs are discrete points in a continuous space of input-output relations. This may present problems when these LUSTs are offered to an optimisation model. The resulting optimal combination of LUSTs is then not necessarily the 'true' (or global) optimal land use. The closeness of the LUST-based solution to this 'true' optimum, depends strongly on the alternative management practices in the LUSTs offered to the optimisation model. The range of management practices included in the LUSTs require therefore careful consideration. In general, not only actually occurring land use systems should be described, but also alternative options, to facilitate analysis under other than present day conditions. This might call for quantification of possible substitutions for one type of input by another. For example, the use of herbicides and other biocides can be reduced by using more labour for manual weeding or for better checking of the field to enhance the efficiency of application of biocides and allowing a reduction in the required amount. Similarly, the efficiency of fertiliser application can often be enhanced by applying more frequently, thereby reducing the total amount of fertiliser needed. Formulating alternative LUSTs often requires guestimation of input-output relations on basis of sometimes contradicting or unclear, and often scarce information. Similarly, obtaining information on actually occurring LUSTs is often difficult, due to the often unclear specification by farmers of operations and (quantity of) inputs and outputs. Interpretation and generalisation of the information from a group of farmers is often problematic, due to the diversity of management practices, and the sometimes obscure, or lacking, rationale behind certain of these practices. This is a general problem in farm analysis. However, by describing all the operations and their inputs and outputs in a LUST, the results of assumptions and interpretations are made clear, and as such can be challenged and, if needed, improved upon.

Although the quantification of the input-output relations of the LUSTs should be based on rationalities, the proposed method of describing land use does not allow the inclusion of formally described explanatory relations. Biophysical conditions (and with these, the effect of management practices on outputs), vary from region to region and from period to period. The LUSTs are therefore only valid for the specific agroecological regions for which they were developed, and then still only for a limited period. To overcome this problem, formally described reasonings in expert systems could be used for generating LUSTs. These expert systems, which could contain simulation models, can be gradually improved and extended, until a dynamic, explanatory description of land use is attained.

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