Modelling

Quantifying economic and environmental trade-offs in land use exploration at the regional level: a case study for the Northern Atlantic Zone of Costa Rica

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Abstract

A generic methodology is presented for exploration of sustainable land use options at the regional level by quantifying trade-offs between socio-economic, sustainability and environmental objectives. The methodology includes a linear programming model, technical coefficient generators for livestock and cropping activities, and a geographic information system. The LP model maximizes regional economic surplus subject to a flexible number of resource, sustainability and environmental constraints. Sustainability is measured in terms of soil N, P and K balances, and environmental performance through indicators of pesticide use, nutrient losses and a proxy for trace gas emissions. The

methodology's capabilities are illustrated for the Northern Atlantic Zone of Costa Rica. Though ample scope exists for reducing environmental effects and introducing sustainable production system separately, pursuing both objectives simultaneously considerably reduces economic surplus and agricultural employment. Agricultural area can be decreased and forested area increased without severely affecting regional economic surplus.

Introduction

Traditionally in most countries, issues surrounding the debate about the development of the agricultural sector center around the question of how to achieve a certain level of food security while simultaneously providing sufficient income for food producers (Timmer et al., 1983). More recently, another concern has entered the debate, i.e., that of environmental protection (Kuyvenhoven et al., 1995; Spiertz et al., 1994). Land use has obvious implications for farm income and the various dimensions of sustainability and environmental impact. The latter mainly involve the environmental effects of agricultural production, such as pollution by nutrient losses, environmental effects of pesticides and trace gas emissions. There exists a lack of tools and models that are capable of quantifying trade-offs that occur between various objectives in general and those between economic-related, sustainability-related and environmental-related objectives in particular (Crissman et al., 1997). The main challenge in the development of such methodologies consists of the integration of bio-physical with socio-economic information, which is the topic of this paper. A methodology is presented for the exploration of sustainable land use options at the regional level by quantifying trade-offs between socio-economic, sustainability and environmental objectives. The methodology is called SOLUS (Sustainable Options for Land USe), and was developed by the Research Program on Sustainability in Agriculture (REPOSA) in Costa Rica. SOLUS evolved from the USTED (Uso Sostenible de Tierras En el Desarrollo; Sustainable Land Use in Development) methodology that operated at the level of the settlement (Schipper et al., 1995; Stoorvogel et al., 1995) and was gradually scaled-up via the district level (Jansen et al., 1997a) towards the level of an entire region as presented in this paper. The methodology is illustrated with a case study of the Northern Atlantic Zone (NAZ) of Costa Rica. The next section introduces the NAZ and formulates the central research question; the third section explains the SOLUS methodology; the fourth section discusses results; and the final section presents a summary with conclusions.

The Northern Atlantic Zone of Costa Rica

Site description

The NAZ is in the Caribbean lowlands of Costa Rica, and our specific study area covers the northern half of the province of Limón , roughly between 10°00' and 11°00' latitude and 83°00' and 84°00' longitude. (Figure 1). The humid tropical climate is characterized by a mean daily temperature of 26 °C , a mean annual rainfall of 3500-5500 mm, and average relative humidity of 85-90%. All months of the year have a precipitation surplus. The elevation varies from sea level to 400 m a.s.l. Four major soil groups were distinguished (Figure 2), based on criteria of fertility and drainage: *i*) young alluvial, well drained volcanic soils of relatively high fertility (Inceptisols and Andisols), classified as Soil Fertile Well drained (SFW), *ii*) old, well drained soils developed on fluvio-laharic sediments of relatively low fertility (Oxisols and Inceptisols), classified as Soil Infertile Well drained (SIW), *iii*) young, poorly drained volcanic soils of relatively high fertility (Entisols and Inceptisols), classified as Soil Fertile Poorly drained (SFP), and *iv*) soils not suited for agriculture including peat soils (Histosols), shallow unfertile mountain soils on sedimentary rock (Inceptisols) and soils developed on volcanic ash under extreme humid conditions (Hydrudands), (Nieuwenhuyse, 1996). The total surface of the study area is about 447,000 ha, 334,000 ha of which is suitable for agriculture. From this 334,000 ha, some 55,000 ha is protected area for nature conservation, so that 279,000 ha is available for agriculture. Table 1 presents an estimation of recent land use based on satellite imagery, aerial photographs and field observations. Land use is dominated by natural forests, cattle ranching and banana plantations; secondary crops include plantain, palm heart, root and tuber crops, maize, papaya, pineapple and ornamental plants.

Regional land use problems

Colonization of the NAZ started in the late 19th century, with a major influx of settlers in the second half of this century. Substantial deforestation has taken place after which soils were mostly used for extensive cattle ranging and large-scale banana cultivation (Veldkamp et al., 1992). Negative environmental effects of tropical deforestation have been reported to include bio-diversity loss, land degradation and increased emission of trace and greenhouse gasses such as CO_2, N_2O, and NO (Detwiller & Hall, 1988; Houghton, 1991; Keller et al., 1993). Due to the extensive nature of cattle ranging with low external inputs, coupled to relatively high stocking rates, soil mining and resulting pasture degradation has become a serious problem in the area (Hernandez et al., 1995; Ibrahim, 1994). Carrying capacity of most natural pastures continues to decline as fields are becoming more and more infested by weeds, resulting in decreasing returns to livestock keeping (Jansen et al., 1997b). During the past few years, low beef prices have aggravated the situation for cattle farmers. While current practices of cattle ranging in the NAZ are unsustainable, since 1987 crop farmers have been faced with a drastic change in agricultural policy by the Costa Rican government as a result of the introduction of a structural adjustment program. Both consumer subsidies and producer support prices on basic food staples such as rice, maize and beans were gradually abolished. At the same time, in an effort to increase foreign currency earning, emphasis was put on the cultivation of non-traditional export crops such as palm heart, root and tuber crops, and ornamental plants. These policy changes have put pressure on farmers' income. A recent concern in the NAZ is raised by environmentalists who signal various threats to the remaining natural forests and protected areas in the area. For instance, the relatively large amounts of pesticides used in the area, especially in the cultivation of bananas, ornamental plants and some field crops (Jansen et al., 1998), may pose a threat to the 'health' of the ecosystem in general (Castillo et al., 1997), and of humans in particular (Wesseling, 1997). Also, the expansion of agricultural land - especially extensive range land systems - causes land use conflicts in buffer-zones around protected areas and natural parks (de Vries, 1992). Finally, Costa Rica is faced with an increasing unemployment rate and crowding of its big cities in the Central Valley, so that employment in agriculture is of general concern to the government.

Based on the above problem statements, the central question posed in our case study is to find out the scope for sustainable land use in the NAZ by taking into account considerations of income, employment, sustainability and environmental effects.

Methodology

SOLUS involves integration of a number of techniques and models, Figure 3. The core of the methodology consists of *i)* a linear programming (LP) model, called REALM (Regional Economic and Agricultural Land use Model), *ii)* two so-called Technical Coefficient Generators (TCGs), one for cropping activities called LUCTOR (Land Use Crop Technical coefficient generatOR) and one for livestock activities called PASTOR (PASture and livestock Technical coefficient generatOR), and *iii)* a Geographic Information System (GIS). Even though LP models are often used in exploratory land use studies (e.g. de Wit et al, 1988; Hazel & Norton, 1986; Rabbinge & van Latesteijn, 1992; Veeneklaas et al., 1994), a salient characteristic of the use of LP in SOLUS is that it integrates knowledge on bio-physical and socio-economic processes which allows the assessment of trade-offs between economic-related and other objectives at the regional level. REALM selects land use options from a large number of alternatives (*i.e.*, crops and livestock options) while maximizing regional economic surplus subject to certain boundary conditions and restrictions as goal constraints. The latter are related to the available amount of land (specified by soil type) and labour resources, marketable volumes of products, and sustainability and environmental considerations. The maximized objective under a set of coherent restrictions and boundary conditions, is called a scenario. Trade-offs between economic, sustainability and environmental objectives are quantified by running REALM for different scenarios. Land use options to 'feed' REALM are generated by LUCTOR and PASTOR, and are quantified in terms of so-called Technical Coefficients (TCs). TCs are inputs and outputs of production systems and include such things as yield, costs, labour use, and sustainability and environmental indicators. Crop options as generated by LUCTOR are defined as combinations of a land unit and a crop with a specified technology, called LUSTs (Land Use Systems with a defined Technology; Jansen & Schipper, 1995). In the livestock sector, three systems are defined: PASture production systems at a defined Technology (PASTs), Animal Production Systems (i.e., herds) at a defined Technology (APSTs), and Feed Acquisition Systems at a defined Technology (i.e., feed supplements) (FASTs). The relationship between APST, PAST and FAST is illustrated in Figure 4. Only LUSTs and PASTs are truly land-based production systems. Whereas LUSTs and APSTs generate marketable products, PASTs and FASTs generate nutrients and energy to feed cattle in APSTs and are, in this sense, intermediate systems. All systems describe specific quantitative combinations of physical inputs and outputs, thus representing fixed input-output technologies. Finally, GIS plays an important role in archiving and manipulating geo-referenced input data and in presenting spatial output results. There is a semi-automated flow of data between the GIS, the TCGs, and the LP model.

GIS

A GIS (PC ArcInfo and ArcView) is used to store, geo-reference and manipulate bio-physical and socio-economic data (Stoorvogel, 1995). Map layers were created for soil type, climate characteristics, topography, rivers, road infrastructure and administrative boundaries (Stoorvogel & Eppink, 1995). Because of spatial variation in land characteristics, a regional area under study generally needs to be stratified. In the NAZ, soil types, climatic characteristics and major topographical features are distributed rather homogeneously throughout the area, and there is no need for zonation based on bio-physical characteristics. However, road infrastructure varies considerably, ranging from a relatively high quality and dense network in the southern part to a relatively low one in the northern part. Since road infrastructure affects product transportation costs, which is a major determinant in the economics of production, this feature was used in zonation of the NAZ. Based on road quality and geographical distances between farm gates and market outlets, transportation cost models were developed for different classes of products (Jansen & Stoorvogel, 1998). These models were used to stratify the NAZ into 12 sub-zones using procedures available in GIS (Figure 5). Product transportation costs for the sub-zones are summarized in Table 2. For each sub-zone, soil and labour endowments were calculated by map overlaying (Table 3). Agricultural labour availability per sub-zone was derived from overlaying with administrative boundaries linked to the most recent population census data (DGEC, 1987) and zone-specific population growth rates (DGEC, 1997). Labour mobility costs between sub-zones were calculated on the basis of bus fares between centres of the sub-zones.

Technical Coefficient Generators: LUCTOR and PASTOR

TCs are generated using the so-called 'target oriented' approach (Van Ittersum & Rabbinge, 1997). This approach entails that target production levels are predefined and that subsequently the amount of required inputs are quantified by a TCG, in our methodology LUCTOR and PASTOR. E.g. for crops and pastures, target production levels 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., fertilizers, crop protection agents), for the first and the last case respectively. The calculation of inputs is based – as far as possible - on knowledge of physical, chemical, physiological and ecological processes involved. When process knowledge is incomplete/absent, calculations are based on expert knowledge, literature data and field observations. In addition to the target production levels, the technology used to realize them is specified. For example, certain operations may be performed either with machines, manually or using a combination of both. The technology used may affect yield, costs, labour requirements and environmental impact. Target production levels, technologies and relationships between inputs and outputs are land type specific and are therefore geo-referenced. In the case of animal production systems (i.e., APSTs), target production levels are operationalized via target live weight gains and reproduction characteristics. Animal production technologies vary with respect to herd maintenance (e.g., degree of health care given) and marketing (*i.e.*, selling/buying) strategies. By combining various target production levels with different technologies, LUCTOR and PASTOR generate TCs for alternative production systems at a defined technology.

Four categories of TCs are distinguished: *i*) economic, i.e. costs of production and labour use, *ii*) physical production, *iii*) sustainability indicators, and *iv*) environmental effect indicators. Marketable output is only generated for LUSTs (crop yields) and APSTs (meat), and is specified to quality classes and market destination (domestic, export). Each APST is characterized by its feed requirements in terms of metabolizable energy, crude protein, and phosphorus, which are calculated using the equations for beef cattle as presented by the National Research Council (NRC, 1996). PASTs and FASTs generate intermediate output in the form of cattle feed, in the same terms as used to specify feed requirements of APSTs. Whereas the economic and the production TCs are fairly straightforward quantities, the sustainability and environmental effect TCs need some elucidation:

<u>Sustainability indicators</u> consist of soil nutrient balances for nitrogen (N), phosphorus (P) and potassium (K). A soil nutrient balance is calculated using an adapted version of the NUTMON model (Stoorvogel, 1993). This model determines soil nutrient balances for N, P and K based on estimates for inputs, such as atmospheric deposition, N fixation, weathering, manure and urine, and outputs, such as the amount of nutrients removed in harvested products and by grazing, and losses by leaching, volatalization and denitrification/nitrification. Negative balances imply soil mining, causing the simulated crop or pasture production system to be unsustainable in the long run (in the sense that target yield levels cannot be maintained). Actually occurring production systems are often classified as unsustainable. Alternative, sustainable production systems are modelled by

LUCTOR and PASTOR by imposing zero soil nutrient balances for N, P and K for given target production levels. The TCGs then calculate the amount of fertilizer needed to maintain these zero nutrient balances. For PASTOR, there is the option to model grass-legume mixtures with a closed soil nutrient balance for N only. For each crop and pasture land use type in this study, both unsustainable (often synonymous with actual) and sustainable (i.e., alternative) systems are modelled.

Environmental effect indicators consist of two groups. The first consists of N losses to the environment via leaching, volatilization and denitrification/nitrification. Whereas volatilization of N via ammoniac results in acid rain, leached N is a potential soil water pollutant, and denitrification/nitrification losses of N via N_2O and NO add to the greenhouse gas effect (Keller et al., 1993). Simulated losses are largely based on generalized measures and expert estimates, even though efforts are currently being made to base the calculations on process-based simulation models. The second group of environmental indicators is related to pesticide use and consists of an ordinal so-called Pesticide Environmental Impact Index (PEII; Jansen et al., 1995), and the total amount of active ingredients used (PAI). Even though the latter is relatively easy to monitor and much used, it is not a particularly appropriate indicator as active ingredients differ considerably with regard to their environmental impact (van der Werf, 1996). The PEII takes into account not only active ingredients used but also their degree of toxicity and their persistence in the environment.

Technical coefficients are averages per hectare and per year. For LUSTs and PASTs with a life span larger than one year, annuities are calculated based on the present value. This procedure is needed because even though REALM is a one-period model, the various LUSTs and PASTs are defined for different periods of time (e.g., maize for 4 months, palm heart for 15 years). To obtain an average value for, e.g., physical production or input cost, values over different years were discounted back to the present and added, after which the resulting value was transformed into an annuity (Schipper, 1996). This procedure can be justified by arguing that at any given time one can expect a wide range of stages to exist for a given land use type in the region.

A qualitative land evaluation (Figure 3), combined with expert knowledge, was used to determine which crops and pastures have (bio-physical) potential in the NAZ. LUSTs were created for banana, black bean, cassava, maize (grain and fresh cobs), melina tree plantation, palm heart, pineapple and plantain. Next to 'actual' (soil nutrient mining) systems for each crop, seventy-two alternative technology levels were defined by combining nine levels of input for fertilizers with two levels (low and high) for pesticides (i.e. insecticides, fungicides, nematicides and herbicides) and mechanization. These combinations correspond to target production levels ranging from certain minimum levels to maximum attainable production. For melina tree plantation, only one alternative technology was defined that includes high fertilizer input and one level of herbicides. All alternative systems have zero soil nutrient balances for N, P and K.

PASTs were modelled for five pastures: unfertilized natural grass, unfertilized grass-legume mixtures, and the fertilized improved species Estrella (*Cynodon nlemfuensis*), Brachiaria (*Brachiaria brizantha*), and Tanner (*Brachiaria radicans*). Grass-legume mixtures were only modelled for the well drained soil types SFW and SIW, since no grass-legume combination is known to be persistent on poorly drained soils in the NAZ. For the natural grass and the grass-legume mixtures, TCs were generated using 13 different stocking rates ranging between 1 and 4 AU ha^{-1} (1 AU = animal unit of 400 kg liveweight), in steps of 0.25, resulting in 13 alternative options for each grass species and soil type. For each of the fertilized species, TCs were generated for the combination of 21 stocking rates ranging between 1 and 7 AU ha^{-1} in steps of 0.25 and 20 fertilizer application levels ranging between 0 and 100% of the amount to reach maximum attainable production, in steps of 5%. This resulted in 420 alternative pasture options for each grass species and soil type. The natural pasture was characterized by soil nutrient mining, whereas the grass-legume mixtures had a closed soil N balance and the fertilized pastures had closed soil N, P and K balances. Weeds were managed in all pastures by a mixture of manual weeding and herbicides, except in the grass-legume mixtures where only manual weeding was applied.

For APSTs, separate beef breeding and beef fattening systems were defined with target animal growth rates ranging from 0.5 (about current mean NAZ growth rates) to1.0 kg hd^{-1} d^{-1} (feasible high growth rates). FASTs included feed supplements of green rejected bananas, sugar cane molasses, two types of chicken-dung based concentrates, and a P mineral salt.

All inputs and outputs were carefully reviewed by a number of experts in the field, and generated TCs were validated against field observations, literature data, and well-established knowledge on agronomic relationships.

Linear Programming model: REALM

REALM selects, per sub-zone and per soil type, the optimal combination of LUSTs, APSTs, PASTs and FASTs by maximizing regional economic surplus, subject to user defined restrictions and boundary conditions. Economic surplus is defined as the sum of output value (i.e., quantities of crop and livestock products times their corresponding farm-gate prices) minus production costs, where the latter consist of input costs (i.e., costs of fertilizers and pesticides, annualized costs of capital items such as machinery, corals etc.) and labour costs. Boundary conditions and restrictions in REALM include the following:

Livestock balances. A feed balance restriction ensures that feed requirements of the selected herds (APSTs) are met by a combination of pasture (PASTs) and supplementary feeds (FASTs). An animal number balance equates the total number of animals in the selected herds to the amount of pastures selected times the selected stocking rates on these pastures. Because it is assumed that there is no outside influx of animals into the NAZ, a balance restriction equates the number of animals purchased in the fattening systems to the number of animals raised in the breeding systems.

Land and labour resources. Soil use balances restrict the total area of selected LUSTs and PASTs to the available area for each soil group. As to labour resources, it is assumed that in each sub-region there is a certain availability of agricultural labour at a fixed mean wage. This labour can also work in other sub-regions, be it that in that case mobility costs are taken into account. Movement of labour within each sub-zone is assumed to occur at no cost. The derivation of the labour force and mobility costs between sub-zones is described in the section on GIS (see above). It is assumed that extra labour can be drawn from the non-agricultural labour force in the NAZ and from outside, but at a certain cost. The wage is fixed at the present mean wage up to 20% of the NAZ agricultural labour force, and thereafter the function is linear and upward sloping with an supply elasticity of 0.2. This way the agricultural sector competes for labour with other economic sectors.

Market constraints. For a number of products, i.e. bananas, palm heart, plantain and meat, the share in the national supply of the production originating in the NAZ is large (Jansen & van Tilburg, 1996). For some products, i.e. bananas, fresh pineapple and palm heart, the supply from the NAZ is even a considerable part of the world supply. For instance, while Costa Rica is responsible for around 15% of world banana exports, 95% of all banana plantations in Costa Rica are located in the NAZ. Therefore, one can assume that the price of these products is influenced by the supply from the NAZ as the demand for these products is limited. A method presented by Hazell & Norton (1986) was used to incorporate variable prices by linearising so-called downward-sloping demand functions around an observed quantity and price. The parameters used for each product are a base price and quantity, a price demand elasticity, the share of the supply from the region in the national supply (under the base situation) and a price supply elasticity of the remaining regions (those regions outside the model). The price demand elasticities were taken from Geurts et al. (1997). Base price and quantities, including the share of the region in the national and international supply are based on 1996 figures (Jansen & van Tilburg, 1996). Since supply elasticity estimates for the crops considered in our study do not exist for Costa Rica, an assumed value of 0.2 was used, indicating that producers in other regions are not very sensitive to price changes. REALM selects the best price-quantity combinations for all products taken together, thereby maximising the sum of producer and consumer surplus.

Sustainability and environmental effects. REALM includes restrictions on soil nutrient balances and environmental effect indicators that can be either implemented or discarded, depending on the scenario being run (see below).

Prices and the labour wage used were mean values for the period 1994-1996 corrected for inflation. Farm gate prices were calculated by subtracting transportation costs from wholesale prices, and as such are geo-referenced. Annuity costs were calculated using the capital recovery factor with a discount rate of 7% (value based on Zuñiga (1996a,b).

Scenarios

To address the central research question raised earlier for the NAZ, a number of scenarios were evaluated in comparison with a so-called base scenario. This base scenario maximizes regional economic surplus with constraints consisting only of land and labour resource limitations and market functioning. No restrictions on neither sustainability nor on environmental parameters are included. Next to the base scenario, six scenarios were constructed to quantify trade-offs between economic, sustainability and environmental goals, as follows:

- Two environmental scenarios, operationalized with a restriction that limits the maximum values of the environmental indicators (i.e., all loss components of N to the environment, and both pesticide use indicators) to respectively 80% (scenario 1) and 50% (scenario 2) of their base run values;
- Two sustainability scenarios, operationalized with a zero N soil balance (scenario 3) and with zero soil N, P and K balances (scenario 4);
- Two combined environmental and sustainability scenarios, operationalized with zero N, P and K soil balances in addition to the restriction that limits environmental effects to 80% (scenario 5) and 50% (scenario 6) of their base run values.

Results and discussion

Table 4 presents the main results of the scenario runs. As far as land use is concerned, it should be remembered that 38% of the total land area in the NAZ is unsuitable for agriculture and remains under permanent forest cover. Any land left unused by the model is assumed to convert to secondary forest and consequently is added to the 38% already existing forest area.

Base scenario

Land use in the base scenario resembles current land use in broad terms (compare Tables 1 and 4) and is dominated by pasture (43% of total area), with some 8% of the area used for bananas. Fast growing cattle (average liveweight gains of 0.8-1 kg $hd^{-1}d^{-1}$) is raised on natural pastures with average stocking rates of 2.25-2.5 AU ha^{-1} with supplementary banana and feed concentrates. The selected stocking rates are a bit higher than current mean stocking rates in the NAZ, i.e. 1.4 AU ha^{-1} in breeding systems and 1.9 in fattening systems (van Loon, 1997). The selected natural pastures deplete soil N at a rate of 60-70 kg ha^{-1} yr^{-1}, which compares well with the value of 65 as reported by Cadisch et al. (1994) for a case-study in Brazil, and is a bit lower than the estimate of 94 kg ha^{-1} y^{-1} reported for comparable systems in the humid tropics by Thomas et al. (1992). Pesticide use on natural grassland is very low at 0.7-0.9 kg active ingredients (a.i.) ha^{-1} yr^{-1}. Banana is cultivated using the highly fertilizer intensive technology, resulting in zero soil nutrient balances, but high N losses to the environment, i.e. 101 kg ha^{-1} yr^{-1} through volatalization, 227 through denitrification/nitrification and 361 through leaching. Average pesticide use in banana plantations is very high at 53 kg a.i. ha^{-1}, which compares well with the value of about 45 kg a.i. ha^{-1} as reported by Castillo et al. (1997). Other crops selected by the model include cassava (20428 ha) and melina tree plantation (18416 ha). All available land for agriculture is used, while providing employment in the primary production sector to 72% of the total agricultural NAZ work force. Mean pesticide input closely resembles the average value for Costa Rica as a whole of about 6 kg a.i. ha^{-1} (von Düszeln, 1990). In general, land use in the base scenario can be qualified as highly unsustainable, as evidenced by the substantial soil N and K losses. Over time, when soil nutrients become exhausted, yield levels should decline and land use options will be limited to the results obtained under the sustainability scenario no 4 (see below).

Environmental scenarios

Limiting the regional environmental effect parameters to 80% of their base run values (scenario 1) has only a small effect on economic surplus, reducing it to 94% of the base run value. Employment in the primary production sector, however, is more severely affected and decreases to 79% of the base run value. As far as land use is concerned, the only effect of the 20% reduction in regional environmental effect parameters is a 6% decrease in crop acreage, achieved mainly by the elimination of melina plantations and a 20% reduction in banana area. Melina cultivation has relatively low profits and is the first LUST to be taken out of production. Bananas can not be grown without heavy input of pesticides, so the only way to decrease pesticide use in banana is by decreasing its surface area. Further reducing the regional environmental effect parameters to 50% of their base run values (scenario 2) reduces economic surplus and employment to respectively 72% and 54% of their respective base run values. In terms of land used, the most striking effect is a reduction of the total pasture area to 54% of the base run value. As is to be expected when economic surpluses decrease, marginal soils are first being abandoned: all infertile soils (SIW) are taken out of production, whereas only 53% of the poorly drained soils (SFP) and 86% of the fertile well-drained soils (SFW) continue to be used. Technologies used are practically the same as in the base run. It should be noted that, though at the regional level the environmental effect parameters are reduced, at the field level most LUSTs are still characterized by large losses of N to the environment and high inputs of pesticides.

Sustainability scenarios

Sustainable land use in terms of closed soil nutrient balances have a smaller (negative) effect on socio-economic parameters than the environmental scenarios discussed above. While zero soil N balances in scenario 3 lead to an economic surplus and employment of respectively 90% and 104% of their respective base run values, zero soil N, P and K balances (scenario 4) result in corresponding figures of 83 and 95, respectively. The most striking effect of sustainability restrictions on land use is the decrease in area and change in pasture technologies. In scenario 3, about 70% of both SFW and SIW soils are put under grass-legume mixtures with stocking rates of 3.75 and 2.75 AU ha^{-1} respectively, whereas SFP soils are completely taken out of production (because no grass-legume mixture was offered to the model for poorly drained soils). These relatively high stocking rates are additionally supported by high inputs of feed supplements, i.e. 11 kg of green bananas AU^{-1} d^{-1} during the months January-March, and 3.3 kg AU^{-1} d^{-1} during April-December. In scenario 4, 68% of SFW soils are put under fertilized grassland, with a stocking rate of 2 AU ha^{-1}; 22% of SIW are put under a grass-legume mixture with a stocking rate of 2 AU ha^{-1}, aided by feed supplements to keep the soil nutrient balance at zero; and all SFP soils are again taken out of production. Contrary to the environmental scenarios, the reduction in cultivated area does not lead to decreased employment because grass-legume mixtures and fertilized grasslands are relatively labour intensive compared to natural pastures. The most striking effect of the sustainability restrictions on cropped land use is the disappearance of melina plantations and a significant reduction in cassava area. All crops are cultivated using the most fertilizer intensive technology. Except for the PEII, environmental effect indicator values are about equal to the base run values; the increased use of agro-chemicals per unit area of the selected LUSTs and PASTs compensates for the reduction in total cultivated area.

Mixed environmental and sustainability scenarios

Combining the sustainability restriction with a reduction in environmental effect parameters to 80% (scenario 5) or 50% (scenario 6) of the base run values further decreases regional economic surplus. The environmental effect restrictions preclude extensive use of agro-chemicals to satisfy the sustainability restriction. As a result, a significant portion of the agricultural land is taken out of production as reflected by a dramatic reduction in pasture area to 6-16% of the base run value and a severe reduction in crop area to 43-57% of the base run value. Unused land, which by assumption gets converted to secondary forest, is as high as 82% in scenario 5 and 90% in scenario 6. Strikingly, agricultural activities in both scenarios still produce economic surpluses of 81% and 65% of the base run value, respectively. Even though crops are of relatively marginal importance in terms of area, they are responsible for most of the economic surplus. Employment is more severely affected by environmental restrictions than by sustainability restrictions, as is reflected in the fact that scenarios 5 and 6 generate similar employment levels as scenarios 1 and 2, respectively.

Conclusion

SOLUS

The SOLUS methodology enables quantification of trade-offs between socio-economic, sustainability and environmental objectives in explorative regional land use studies. The methodology integrates various tools and techniques of which linear programming, technical coefficient generators and geographical information systems are the most important. The tools and models of SOLUS are sufficiently generic to allow implementation of the methodology to a range of other regions with different bio-physical and socio-economic conditions. Besides a foreseen follow-up analysis with major interest groups and stakeholders in the NAZ, a joint project is currently under way between REPOSA and the Costa Rican Ministry for Livestock and Fishery (MAG) to adapt and use SOLUS in a pilot area on the Pacific side of Costa Rica. Some limitations and specifics of the approach, however, should be born in mind. First, in static, single-period linear programming as used here, the offered land use options as calculated by the TCGs should ideally represent equilibrium situations, requiring the quantification of steady-state input-output combinations (van Ittersum & Rabbinge, 1997). When nonstable systems are generated, such as the unsustainable options used in our study in order to quantify economic trade-offs with stable, sustainable systems, it should be realized that such sustems have a limited life span and that the input-output combinations will change over time. Second, spatial variation is inherent to regional scale levels and should be adequately addressed. Spatial variation can be handled by sub-zoning of the area and geo-referencing input-output relations as shown in this paper. However, there is a limit to the amount of spatial units that can be handled in LP models, and pragmatic solutions have to be adopted for large and heterogeneous areas. Third, temporal variation may exist in prices and yields (as caused by weather variation), and may be perceived by farmers as elements of risk. Hazell & Norton (1986) presented several ways of dealing with risk in LP modelling, which are currently being explored for inclusion in SOLUS (La Rovere, 1997). Finally, the SOLUS methodology is designed to explore options for regional land use and does not pretend to predict or make blue prints for future land use.

NAZ case study

Regional economic surplus for the Northern Atlantic Zone of Costa Rica is maximized when no restrictions on sustainability or environmental effects are imposed. However, selected land use systems in such a pure income-maximization scenario are highly unsustainable as evidenced by high rates of annual soil nutrient losses. In the long run, this will lead to depletion of soil nutrient stocks and declining yields over time. In such a future situation, the only technical options left to generate agricultural output are sustainable ones, varying between zero fertilizer input technologies corresponding to minimum yield levels, to high fertilizer input technologies with associated maximum attainable yield levels (but all with zero nutrient balances). It was shown, however, that under complete sustainability, regional economic surplus and regional employment in the primary production sector can be maintained at about 80% and 95% of their respective base run values. In these scenarios, land use is limited to pasture for beef cattle production (about 19% of total area) and crops (about 12% of total area) with large scale banana plantation as the most important activity. Even though crops occupy only a small area relative to pastures, they generate most of the economic surplus and employment in the region. The scope for sustainable beef cattle production in the NAZ of Costa Rica is small under current productivity levels and prices, as evidenced by the dramatic decrease in pasture area once sustainability restrictions are imposed. Negative environmental externalities caused by N losses, pesticide use and N_2O and NO gas emissions, are, in economic terms, best mitigated by reducing the cultivated area and not by introducing low external input agriculture. However, in such situations environmental pollution may concentrate in relatively small areas. Introducing sustainable agricultural practices while at the same time restricting their environmental effects to half of the base run values, reduces economic surplus by 35% while halving employment. An additional environmental 'gain' in such a scenario which has not been valued economically is the reconversion of former agricultural land to natural forest that would occupy 90% of the total NAZ area. In a recent attempt to economically value various functions of forest in the NAZ, such as production, regulatory and habitat functions, Bulte et al (1997) suggested a total value of 135-160 US\$ kg ha^{-1} yr^{-1}.

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Figure captions for the paper 'Quantifying economic and environmental trade-offs in land use exploration at the regional level: a case study for the Atlantic Zone of Costa Rica', by Bouman et al.

Figure 1. Case study area in the Northern Atlantic Zone of Costa Rica.

Figure 2. Soil resources in the NAZ study area. SFW = Soil Fertile Well drained; SFP = Soil Fertile Poorly drained; SIW = Soil Infertile Well drained.

Figure 3. Structure of the SOLUS methodology. After USTED, Stoorvogel et al., 1995.

Figure 4. Relationship between PAST, FAST and APST.

Figure 5. Sub-zones in the NAZ study area.

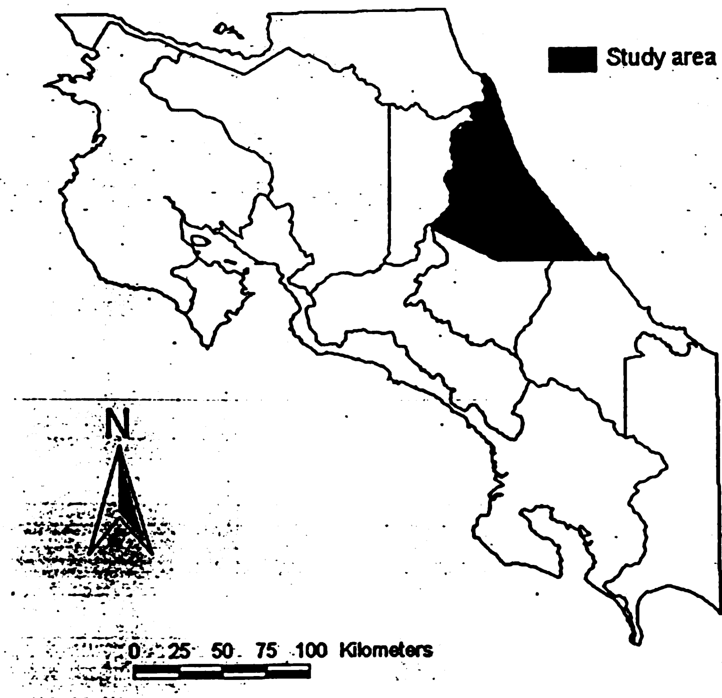

Figure 1.

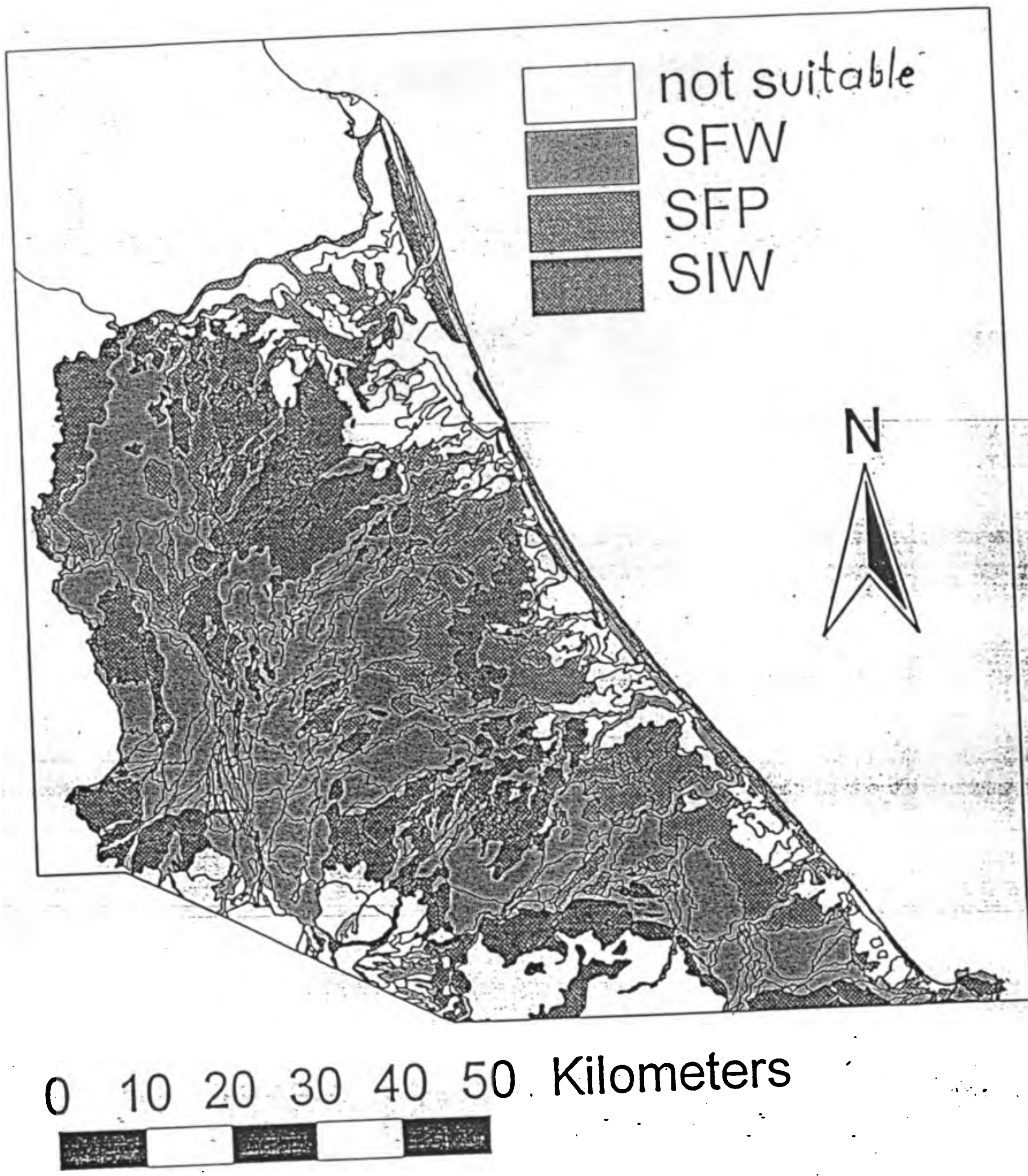

Figure 2.

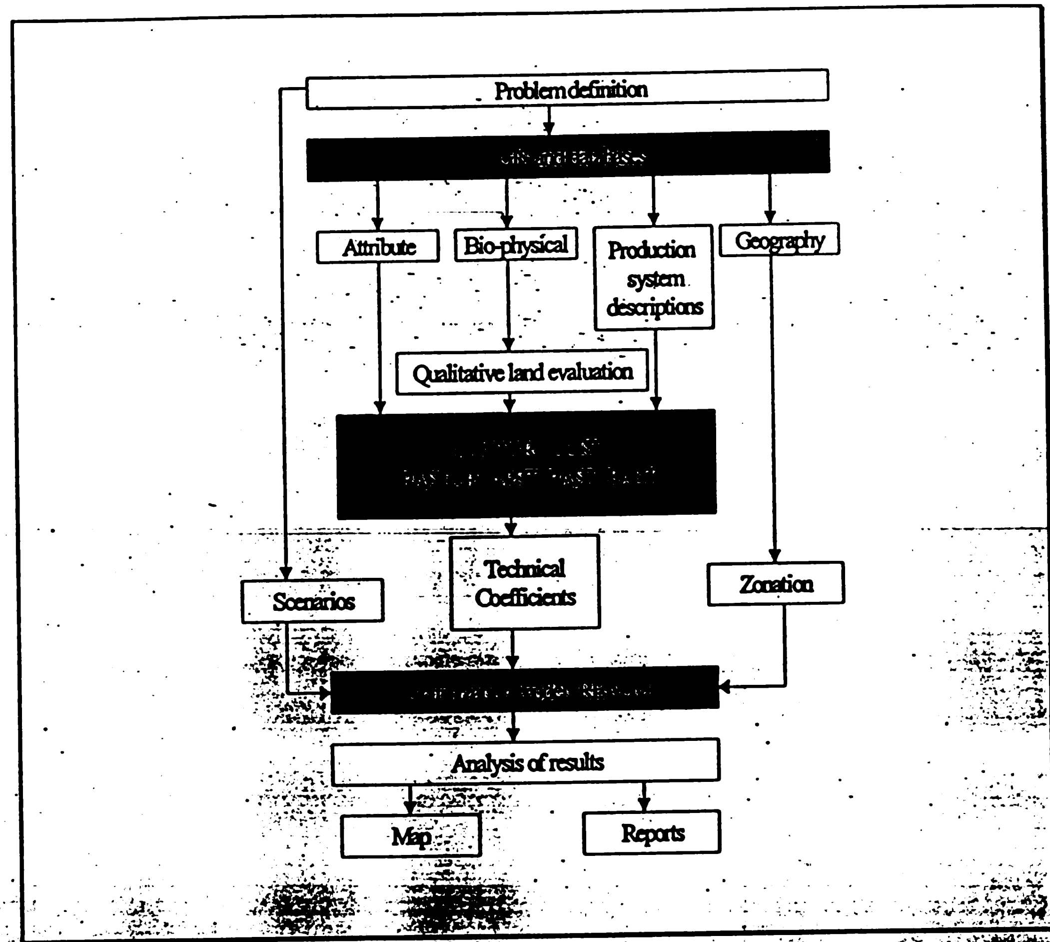
Problem definition
Attribute
Bio-physical
Production system descriptions
Geography
Qualitative land evaluation
Scenarios
Technical Coefficients
Zonation
Analysis of results
Map
Reports

Figure 3.

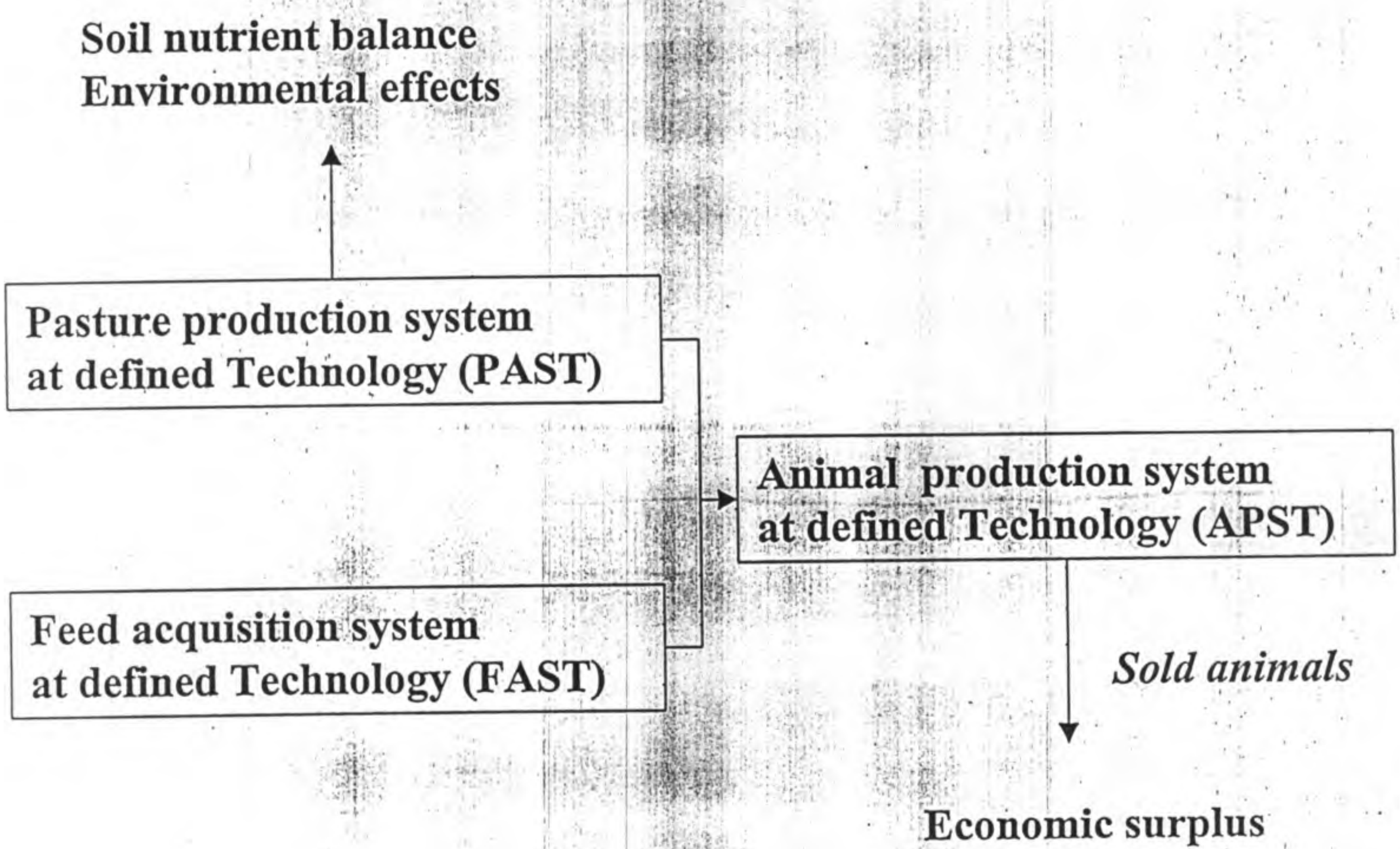
Soil nutrient balance
Environmental effects
Pasture production system
at defined Technology (PAST)
Feed acquisition system
at defined Technology (FAST)
Animal production system
at defined Technology (APST)
Sold animals
Economic surplus

Figure 4

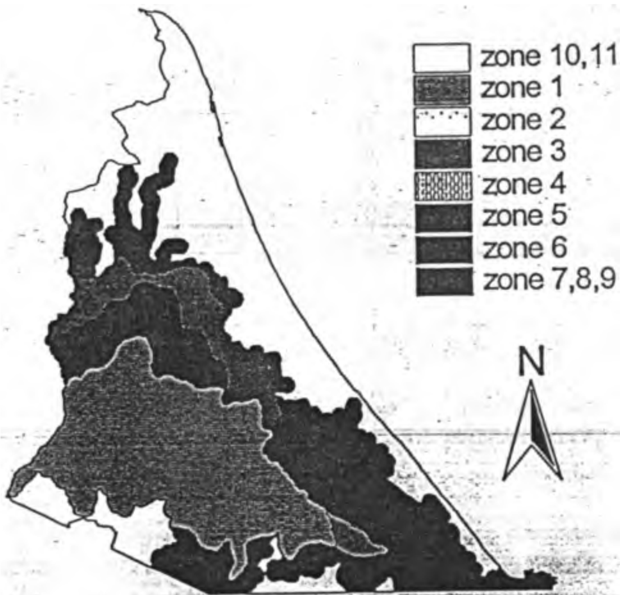

Figure 5. (A better palette will be used!)

Table 1. Estimated actual land use (1992) in the case study area in the Northern Atlantic Zone of Costa Rica (based on Belder, 1994)..

Land use[1]	ha	%[2]
Primary & secondary forest	214054	48
Pasture/beef cattle	174928	39
Banana plantation	42300	10
Crops	15510	3
Total:	446792	100

[1]Surface areas of roads, rivers and villages implicitly included in all land use types
[2]In percentage of total surface area

Table 2. Transport costs in colon per kg product, per product per sub zone. Markets are divided into Domestic and Export market; only timber (Melina) and meat have the same market outlet for export and domestic use.

Zone	Domestic	Export			Domestic, export	
	All crops	*Banana, pineapple*	*Palm heart*	*Maize, beans, cassava, plantain*	*Melina*	*Meat*
1	6.6	0.8	2.5	3	224	2.1
2	6.6	2.3	2.5	7.5	448	2.1
3	6.6	0.8	2.5	3	224	4.0
4	9.6	0.8	5.5	3	224	2.1
5	9.6	2.3	5.5	7.5	448	2.1
6	9.6	0.8	5.5	3	224	4.0
7	9.6	2.3	5.5	7.5	448	4.0
8	9.6	2.3	5.5	7.5	448	4.0
9	9.6	2.3	5.5	7.5	448	4.0
10	24.6	9.3	20.5	28.5	897	7.1
11	14.6	4.7	10.5	14.5	897	5.6
12	14.6	4.7	10.5	14.5	897	5.6

1 US$ = 181 colon; mean 1994-1996 price corrected for inflation.

Table 3. Area available for agriculture (i.e., not having a protected status) per soil type (in ha), and agricultural labor pool (in number of persons) per sub zone.

Zone	SFW[1]	SFP[2]	SIW[3]	Labor
1	63437	19711	26365	13942
2	9666	14516	7263	4409
3	1493	1642	812	363
4	276	818	726	183
5	6521	15991	10384	3230
6	11047	41838	9257	11485
7	2662	4004	3432	1817
8	563	3552	141	600
9	667	0	950	250
10	4553	13504	565	1781
11	391	107	33	643
12	1748	0	265	1346
Sum	103024	115683	60193	40049

[1]: SFW = Soil Fertile Well drained.
[2]: SFP = Soil Fertile Poorly drained.
[3]: SIW = Soil Infertile Well drained.

Table 4. Results of REALM for the base run and for scenarios 1 to 6 (see text for explanation)

Scenario	Base	1	2	3	4	5	6
Economic surplus (10^6 US$)	292	277	210	262	241	236	189
Labor[1] (%)	72	57	39	74	69	57	38
Land use:[2]							
Forest (%)	38	43	67	60	69	82	90
Pasture (%)	43	44	23	26	19	7	2
Crops (%)	19	13	10	14	12	11	8
Per crop type:							
Pineapple (%)	0.7	0.54	0.49	0.63	0.65	0.61	0.54
Palm heart (%)	1.57	1.19	1.24	2.88	1.73	1.73	1.62
Melina (%)	4.12	0	0	0	0	0	0
Banana (%)	7.86	6.12	3.85	8.13	8.13	6.81	4.24
Plantain (%)	0.36	0.30	0.22	0.19	0.16	0.14	0.10
Cassava (%)	4.57	4.43	4.44	1.72	1.72	1.72	1.78
Beans (%)	0	0	0	0	0	0	0
Maize (%)	0.02	0.01	0.02	0.02	0.02	0.02	0.02
Number of animals:							
Fattening system (AU)	317868	301584	160287	271070	133460	57689	30686
Breeding system (AU)	92640	87894	46714	79001	38896	16813	8943
Sustainability indicators:[3]							
NBAL (kg ha^{-1})	-62	-50	-29	0	0	0	0
PBAL (kg ha^{-1})	1	1	0	0	0	0	0
KBAL (kg ha^{-1})	-20	-14	-10	-33	0	0	0
Environmenatl effect indicators:[4]							
NDEN (kg ha^{-1})	41	31	20	40	37	31	20
NLEA (kg ha^{-1})	94	75	47	118	92	65	44
NVOL (kg ha^{-1})	24	20	12	22	23	17	12
PAI (kg ha^{-1})	8	6	4	7	7	6	4
PEII (-)	264	211	132	96	98	40	25

[1]: *labor employment in the primary production sector in % of total agricultural labor force available.*

[2]: *land use in % of the total of 447000 ha. The land use class 'forest' comprises the 38% surface area permanent under forest, plus the land left unused by agriculture by REALM.*

[3]: *sustainability indicators: NBAL = soil nitrogen balance, PBAL = soil phosphorus balance, KBAL = soil potassium balance.*

[4]: *environmental effect indicators: NLEA = amount of nitrogen leached, NVOL = amount of nitrogen volatilized, NDEN = amount of nitrogen lost by denitrification/nitrification, PAI = amount of active Pesticide Ingredients Applied and PEII = Pesticide Environmental Impact Index.*