

Modeling the Sustainability of Agro-Pastoral Land Use Systems with GIS

Model Development and Case Study of Semi-Arid Communal Land Areas in Zimbabwe

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1. Abstract

A GIS-based balance model is presented ("SUSGIS") which allows evaluating whether fertilization requirements of (subsistence and cash crops) of management units like village territories can be met. Nutrient availability is calculated from two main sources: Purchase of chemical fertilizers based on agricultural income from cash crop production ("Supply A") and nutrients derived from organic matter, and more specifically from manure in an agro-pastoral system ("Supply B"). Conversion of supply and requirement of individual nutrients is done on a monetary basis. The final output are maps indicating the sustainability of land use expressed as percent of fertilization supply over requirements for the management units.

The model is constructed in such a way that staff involved in regional to local land use planning like district officers, agricultural researchers and possibly extension workers can evaluate the effect on sustainability of relevant risks and management related factors:

- impacts of risks of crop losses
- the impact of varying ratios between cash crops and subsistence crops
- the impact of different fertilizer requirements for chosen target yields/ cropping systems
- the impact of the relative size of crop and rangeland areas
- the potential impact of rangeland improvement
- the potential impact of changing the grazing system, manure production and recovery factor
- the impact of changing prices of agricultural inputs (costs) and of agricultural products
- the impact of increasing population numbers
- the impact of minimum income / wages / standards of living to be met

Variables can be altered to calculate various scenarios for land use planning. A number of short cuts in model calculations are applied in order to avoid unnecessary complexity, and allow the user to maintain an overview about the main factors involved.

The model can use different spatial or non-spatial data sources, such as tables, maps or remote sensing images. Alternative methods for parameterization of variables is given. It is

currently implemented as a batch file in a GIS system under DOS and also as a spreadsheet version.

It is intended to further test and expand the model for other semi-arid areas, to create a version for script language in a windows based GIS system and to expand it for optional use with additional sub-models for other land use systems, eg. for agro-forestry systems.

2. Justification : Need for Nutrient Management in Agro-Pastoral Systems

Agro-(silvo)-pastoral land use systems in semi arid zones are among the most threatened ecosystems of the world. Systems studied by the authors as a basis for model design include areas in Tunisia, Burkina Faso, Mali, Niger, Kenya, Zambia, Zimbabwe, Uganda, Madagascar, Thailand and India. In most cases, not (only) climatic factors, but bad management triggers off a process of degradation, with the final effect of desertification (Groten, 1991). As a result of relative or absolute overpopulation, political conflicts or colonial occupation, immigration into semi-arid high risk areas and change of land use systems has taken place in many countries. Especially during periods of drought and famine, re-migration occurs to areas more accessible to food aid (Groten, 1996).

An example of a degradation spiral is the increase of run-off on loamy soils after destruction of the cover through overgrazing, enhanced by crust development (Karnieli & Tsoar, 1996). During drought years, the vegetation cover in protected areas with sandy soils has proven to be close to normal (PA-CILSS, 1985). The PPS project of Breman et al (1984-1995) demonstrated, that even in dry zones and years, productivity could be enhanced by phosphate and nitrogen supply on impoverished soils. Many development programs in developing countries are focusing on intensification of agriculture and crop - livestock integration . This intensification in semi-arid zones meets many difficulties related to the high economic risks and risk minimization strategies of farmers, leading to reduced productivity.

Instead of an increase of world use of fertilizers, a net decrease of fertilizer use was found in 1995/1996 (Brown, 1996). The "green revolution " has failed, especially where subsistence economies still are predominant due to high population pressure, a high percentage of the population involved in the agricultural sector, and markets that are far away. As shown by the present conference, the problem of nutrient depletion and non-sustainable land use has gained attention.

Economic and ecological sustainability cannot be separated in half - open agricultural systems, where partly money for fertilizers is generated from cash crop production (as in the study area in Zimbabwe), or by off farm activities or pastoral production. Organisational and social sustainability of these farming systems depend largely on the economic and ecological viability: if the productivity of the overall system deteriorates or decreases per capita, internal or external conflicts are inevitable.

Local conflicts over land and grazing rights often not only concern water, but also access to biomass or more basically, to nutrients. The following concerns were expressed by parties concerned in some countries to Groten (1991, 1994; Toe, 1991):

- conflicts between farmers and pastoralists on access to productive lowland areas
- conflicts between neighbouring villages on use of biomass (woody, non woody) from protected areas
- conflicts over the use of crop residues for multiple alternative purposes (fuel, compost/ fertilization, thatching, hedges) inside the households
- conflicts because of restriction of transhumance movements by fields placed on animal tracks in order to profit of manure

- conflicts between farmers and pastoralists over the use of biomass for composting or grazing, and over extension of fields in former pastoral areas
- conflicts within co-operatives concerning prices of fertilizers
- changing governmental policies concerning subsidies of fertilizer (dominant trend: liberalization of markets, lesser subsidies).

Nutrient balance calculations are required for verifying whether the current or intended systems are likely to be ecologically and economically sustainable. Depending on the specific availability and spatial distribution of local resources, the “optimum mix” of nutrient sources and development strategies may differ between villages or other resource user communities. Also the impact of governmental policies and prices of commodities and inputs should be evaluated, and, if possible, predicted.

2.1 The Zimbabwe case study

As a first step, a basic model was designed by Groten and worked out in detail for a communal land areas in Zimbabwe, through the Msc study of Mrs Restituta Bogere from Uganda. The following describes our model as applied to Zimbabwe. In later stages it is intended to apply it to other study areas, and to expand it towards agro-forestry or mixed cropping systems. Currently it is aimed to provide tools and information for regional to local land use planning, and not for individual farm level decisions.

The study area is in the communal areas of Piriwiri and Mupfure, which were set aside for African farmers by European settlers in the 19th century. The communal farming systems are subsistence systems on marginal soils. Given the chronically difficult situation, it is a question, whether apart from political solutions, farming could be made sustainable in these areas.

Pastoralism plays a vital role in the communal farming system, which is based on agro-pastoralism or mixed farming (Anderson et al, 1993, Scoones, 1993). A clear relationship exists between access to draught animals, farming viability and household wealth in the communal areas. Barrett (1992) found ploughing followed by milk production to be the main economic outputs from the communal herd and found that beef off-take was relatively minor. Animal dung in addition plays an important role in the maintenance of agricultural productivity.

The number of animals varies sharply with the relative portion of grazing land within different villages, the effects of two recent droughts and depending on the wealth of the households. At present the number of animals is low because of droughts in 1991/2 and 1994/5. Non-pastoral income comes mainly from cash crop production, which is the second main source for generation of (money for) fertilizers. Food crops (maize mainly) also profit from residual nutrients after fertilized cotton production. Rotation makes that the total amount of cotton cannot be more than 50 % of crop fields. Other cash crops like sunflowers and ground nut are more risky and therefore cultivated by only a minority of farmers (interview with chief Mujinga, Piriwiri Communal land ; Bogere, 1997).

However, some additional fertilizer sources are used which show the relative importance of nutrient supply in the perception of farmers: use of ant hill soil, ash, alluvial soil from a river, green manuring, fallowing and erosion control, although lesser common.

A problem tree was constructed based on interviews and literature, which contributed to the selection of relevant model variables (see fig. 2).

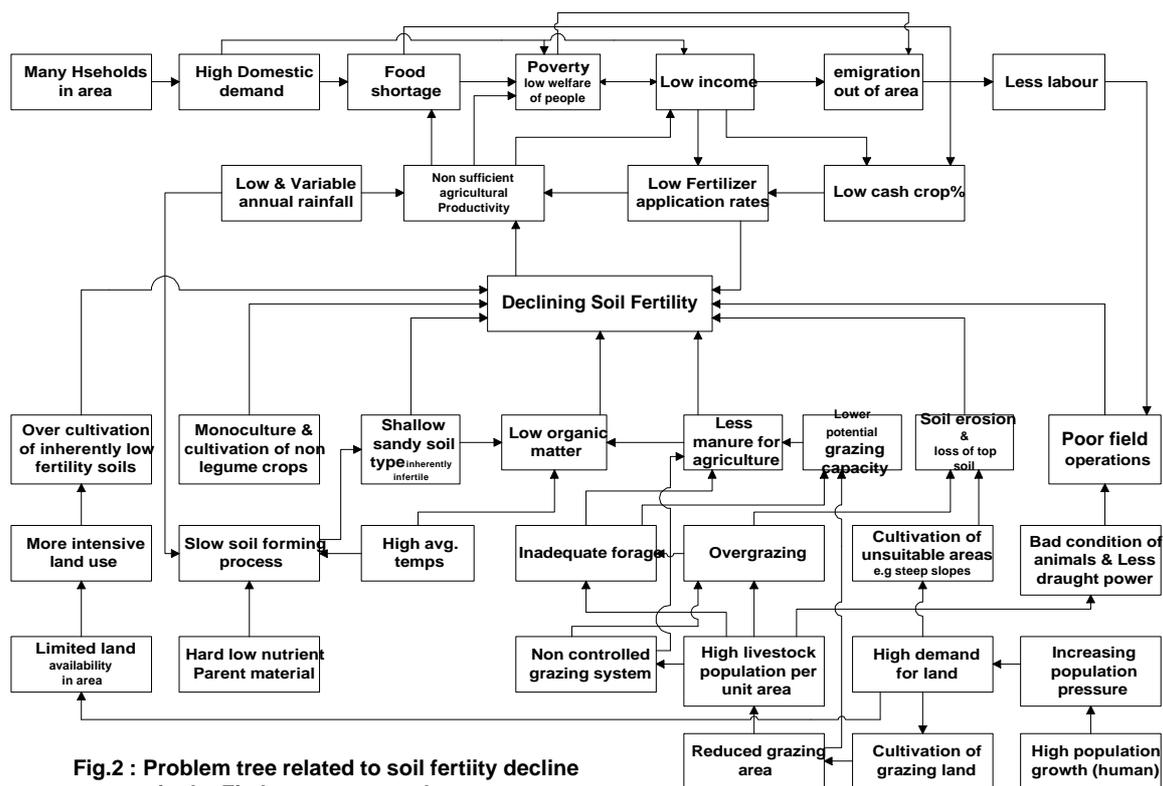


Fig.2 : Problem tree related to soil fertiity decline in the Zimbabwe communal areas

3. Model Design: Selection of Management-and Risk Oriented Model Variables

Although some basic variables, equations and data are shared with some conventional simulation models, the model design differs by a number of basic axioms:

- the model should concentrate on the most relevant variables, especially those related to strongly variable risk or management problems: a problem tree (was used to derive a first set of model variables).
- the variables should if possible be adjustable through management decisions. This would make the model a useful tool for scenario calculations by land use planners and extension services.
- variables, for which data can be obtained easily from existing agricultural and environmental statistics are input data. Target variables are those which are usually not easy to obtain otherwise, except through modeling.
- the number of variables should be increased only if proven necessary. This is based on the assumption that a model with many variables is not necessarily better than one with a less numbers, and that sensitivity analysis of model interactions of ca 200 variables in a simulation model becomes virtually impossible and difficult to use.
- the model should be implementable in a GIS, and use spatially distributed variables as much as possible. The spatial unit for aggregated outputs should be a management unit, e.g. a village territory.
- the model should be transparent to users . Therefore a simplified spreadsheet version including the most important functionalities was prepared first.
- in order to allow use of mixed nutrient sources for sustainable management (e.g. leguminous species, manure, chemical fertilizers), nutrients are expressed in monetary terms.

The model is made up of four sub-models. Variables relevant to management interventions are highlighted as “driving factors” in the flow charts.

1. the fertilizer demand sub-model indicates the total amount of Zimbabwe dollars required to adequately fertilize all cash and food crop fields of a village territory (see fig. 3), according to the governmental recommendations based on existing agricultural research
2. The fertilizer sub-model (or supply A), indicates the total amount of (Zimb.) dollars potentially available from income of cash crop production (esp. cotton), from which were deduced costs of production, risks and household needs at different standards of living (see fig. 4).
3. The manure sub-model (or supply B), indicates the total amount of nutrients expressed in Zimbabwe dollars available estimated from the variable livestock carrying capacity of village rangelands or directly from given animal statistics (the off take dependent on the grazing system (fig. 5).
4. The final balance model expressing nutrients available for fertilization as % of requirements.

4. Discussion of Selected Model Equations

A complete description of the model is found in Bogere (1997). For this paper, some aspects of general interest and alternative options for model implementation will be discussed:

4.1 Discussion of the nutrient demand model:

Driving factors, which are adjustable in the model are crop areas per village and fertilizer rates.

4.1.1 Different methods of crop area estimation

Map data sources for total crop area estimation are either existing soil - land unit or land use maps or satellite images. Usually they don't allow distinguishing between different types of crops. On a case by case basis it has to be estimated which sources are most reliable and accessible to the user. Land use maps are quickly outdated. In the Zimbabwe case a visual interpretation of a Landsat TM image of 1994 was compared with a digital image classification, but finally village statistics were used and individual crop percentages estimated by group interviews with village leaders. Therefore an administrative map was linked to tabular data on village crop statistics. The classical approach to crop area estimation, based on average field sizes per household and demographic data has the disadvantage, that the spatial distribution of fields is unknown and the data quality is often unknown. A more accurate calculation would be the detection of total crop and rangeland areas detected from remote sensing, combined with % (cash) crop estimations using representative transect measurements.

Knowledge of the spatial distribution of agricultural fields and the distance of rangelands to crop fields can be of importance with regard to the grazing system and manure off - take in the GIS manure supply model.

If the impact of population growth is to be investigated, the increase of agricultural areas can be simulated by applying the population growth rate (if land resources are still available).

4.1.2 Recommended fertilizer rates as parameter of nutrient demand

The nutrient demand submodel is based on national fertilizer recommendations derived from agricultural research. Required fertilizer rates (per crop per nutrient type per ha) were therefore not estimated depending on target yields like in the Wofost model (Diepen, van et al., 1988). Levels of governmental fertilizer recommendations were cross-checked by model calculation of Driessen and Bogere and found to be of the correct order of magnitude. Average natural causes for fertilizer gains and losses due to atmospheric deposition, leaching or erosion, are most probably already taken into account in governmental recommendations, based on agricultural on-farm research. Only in exceptional situations a correction may be applied by the model, e.g. in the case of high erosion, flooding or very coarse soil texture.

A soil map would therefore not be used to estimate productivity levels, but, for given productivity levels/ cropping systems, to correct for different levels of nutrient losses, or if governmental recommendations on fertilizer applications are specific per soil type. For sustainable crop production however, nutrient losses need to be minimized on all soil types.

4.1.3 Nutrients and their economic value

According to the recommended fertilizer applications, based on the contents of current fertilizers on the market, the total demand of N, P, K, S, Ca/Mg and B is calculated in metric tons per crop type and per ha per year. Based on the average proportion of nutrients in fertilizers with known market prices, the monetary value of individual nutrients is calculated, and summed per village territory. The same monetary value of nutrients is later used to express the value of kraal manure (or if desired, of compost and green manure). Calculation of the monetary value is preferred to individual nutrient balances, because it allows an integrative approach to sustainability modeling, where natural fertilizers can be substituted by artificial fertilizers bought from different sources of income.

Due to limited time, not all parts of the conceptual model in figures 3 to 5 were implemented in scenario calculations. In the flow chart, the non-implemented parts/variables are indicated by “*alt.”. All constraints (driving factors) that are subject to management intervention are displayed in grey tone. The numbers refer to calculation equations of the more detailed model description (Bogere, 1997).

4.2 The fertilizer submodel (supply A)

Potential availability of (money for) fertilizers is calculated taking into account (see fig. 4):

- net crop production
- optionally correction for crop losses
- product prices per kg
- human population and households
- average domestic requirements acc. to governmental norms for different standards of living
- retail price of fertilizers

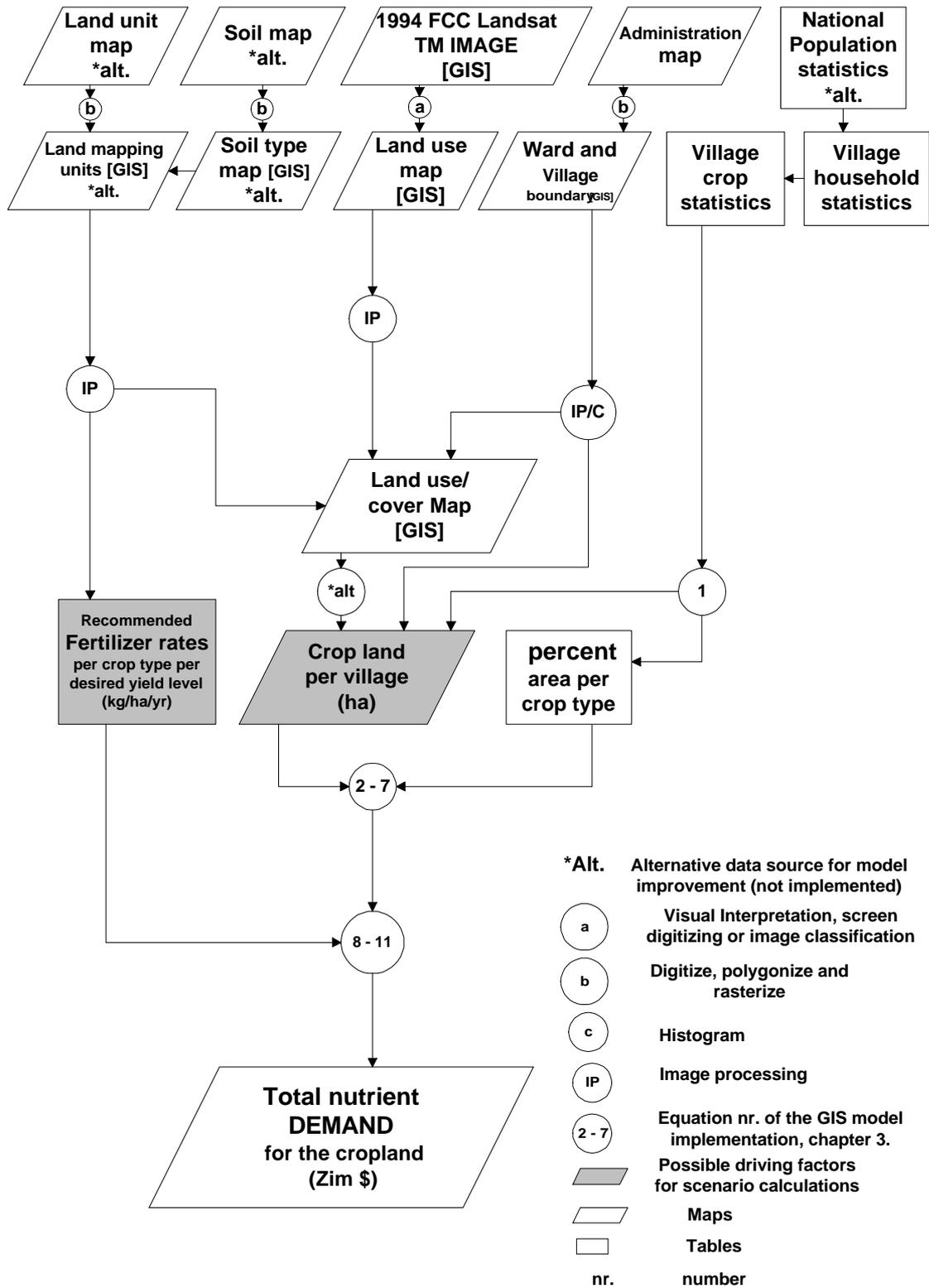


Fig. 3 The fertilizer demand sub model

Fig. 3. The fertilizer demand submodel, which indicates the total amount of (Zimb.) dollars required to adequately fertilize all cash and food crop fields of a village territory according to governmental recommendations

4.2.1 Different ways of assessment of agricultural production

Basically, the model user can apply the following methods:

- use given production statistics per village to evaluate the current situation
- assess production levels from crop areas and recommended fertilizer rates
- if average values of (a) and (b) differ much, reasons must be searched, e.g. crop losses due to pests and diseases (yield gap analysis); then a crop loss factor (fixed or variable as indicator of risks) can be applied, expressed as % loss of crop production
- for scenario calculations optionally the variability of production may be estimated from a rainfall based crop model; if time series of production statistics are available, directly the situation of a bad (e.g. drought) year, normal year and good (e.g. wet year) can be assessed.
- increase of productivity levels from low input agriculture through intensification may be simulated but in this case, also in the demand sub model appropriate fertilizer rates must be used. It should also be critically verified, whether socio-economic situation and ecological risks give any reason for optimism.

4.2.2 Economic strength of households as determinants of (potential) fertilizer availability

In the supply model, natural nutrient sources may completely or partially be replaced by artificial fertilizers.

Since no statistics are available on actual fertilizer use. Therefore, it was estimated from the average financial strength of the farm households. Additional studies would be required to verify, whether our assumption is correct, that if money is available, it could be spent on fertilizers, if norms for average living standards are met. It may be so that priority would be given by farmers to other investments or expenditures. The financial strength of the households in the Zimbabwe communal area strongly depends on cash crop production (cotton) and the relative size of their land. Since the household requirements are influenced by population numbers, the man to land ratio also influences the balance.

Some changes in economic parameters in the sub-model may have an impact on ecological sustainability:

- impact of changing crop yield / productivity levels through intensification
- economic risks of crop losses due to drought, pests and diseases
- changes in farm gate prices (gross value) for cash crops
- changes in variable / production costs e.g. related to different levels of agricultural inputs
- changes in average domestic requirements, e.g.
 - based on data on average income per farmer in the area
 - based on governmental norms like minimum wages
 - based on assessment of area specific monetary needs depending on important expenditures such as school fees, medicine
 - based on evaluation of data on purchase patterns and priorities of population

In principle, through rural credit, saving scheme and through rules of co-operative organization, recycling of income from agricultural production into agricultural inputs can be stimulated.

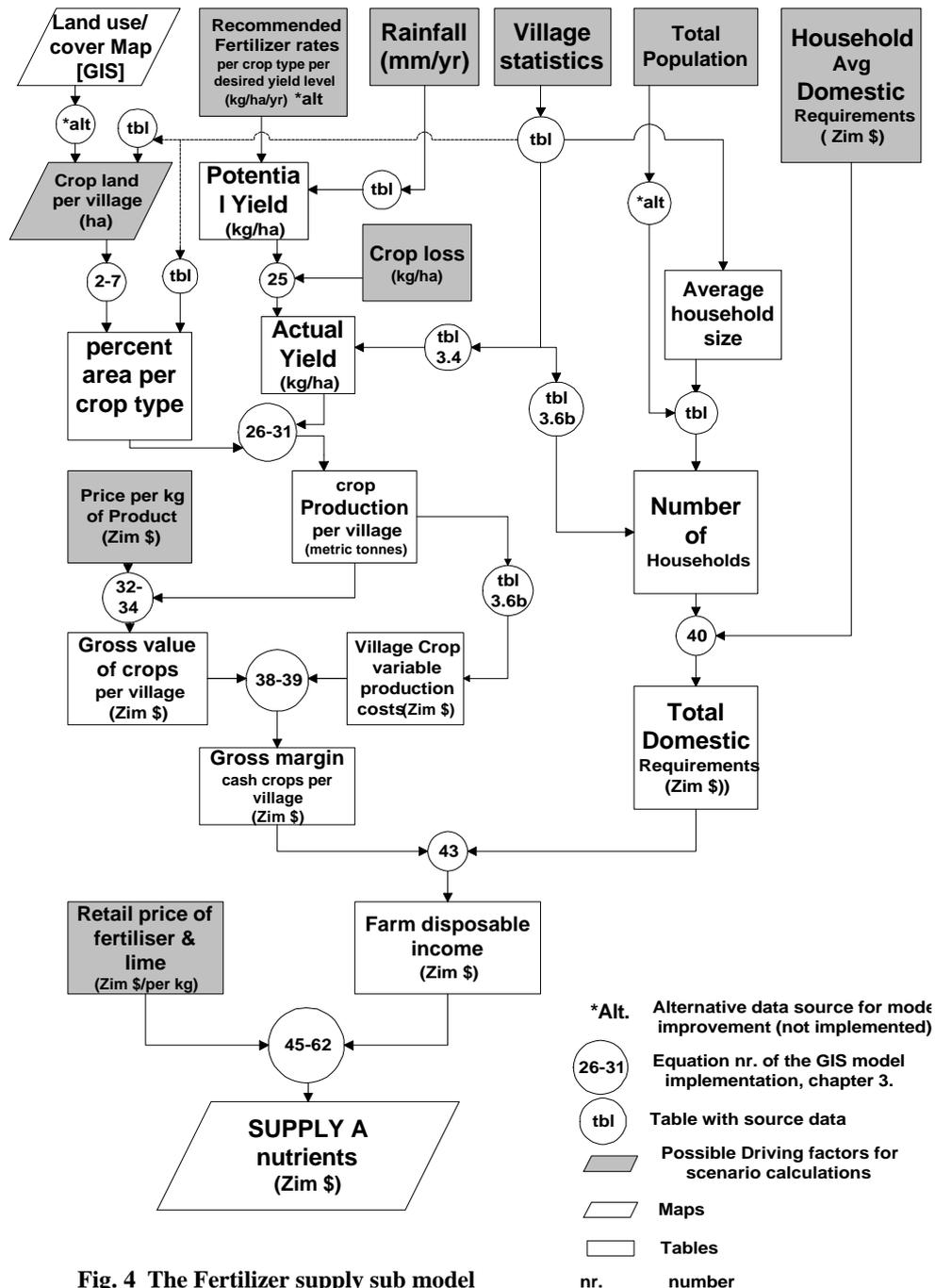


Fig. 4 The Fertilizer supply sub model ("Supply A")

Figure 4. The fertiliser supply sub-model (or supply A), which indicates the total amount of (Zimb.) dollars potentially available from income of cash crop production (esp. cotton) from which were deduced production costs, risks and household needs at different standards of living

4.3 The manure sub-model (or supply B)

4.3.1 The carrying capacity model

Depending on the size of the grazing area and biomass production, the livestock carrying capacity is calculated. Biomass per village territory is estimated optionally:

- a) by a remote sensing based on vegetation index (NDVI data), and field survey
- b) by a rainfall based estimate of biomass production per soil type, if equations are available from literature
- c) by a rainfall based estimate, corrected for different degradation stages, which would indicate the potential effect of rangeland improvement. An indicator of degradation / production levels is the Water Use Efficiency (WUE), called Rain Use Efficiency by some, which is the biomass yield in kg/ha/year divided by the amount of rainfall in mm per year (see detailed literature analysis in Groten, 1991, 1997).

The carrying capacity is the biomass estimate, corrected by a proper use factor (PUF) and divided by the forage requirements of a tropical livestock unit (TMU). The output of this conventional carrying capacity model (FAO, 1983) is an estimate of the (potential) number of animals in the village territory. For simplicity, in the Zimbabwe case, actual animal numbers were used derived from available village statistics. Another reason for the use of actual instead of potential animal numbers was that the actual stocking rate was below its potential, because many animals had died during two recent drought years.

The pastoral component of the model could be further elaborated, according to suggestions for a Ph.D. study by D. Bakary (Agrhymet center). This work may be in line with French research work (Pierre Hiernaux et al., earlier GIS models of rangeland quality and quantity of Koudougou (1993) based on ecological research of the PPS model (Breman et al. 1983 - 1995) in the Sahel, and GIS carrying capacity models applied in Eastern Africa by Toxopeus (1996).

4.3.2 Estimation of manure off-take and its economic value

Thanks to the work of Prof. Scoones and others, a wealth of data on pastoral systems were available in Zimbabwe. Manure off take depends on distances between grazing lands and fields and the grazing system. If a (night) stable system is used in (semi-)sedentary systems, data on manure availability are often available. If not, total manure production is estimated from manure production per animal, known from literature, and the % recovered estimated, depending on the grazing system (Mugwira et al, 1994, Scoones, 1993). Actual manure availability can be estimated based on the proportion of time spent on stubble grazing in fields, in night kraals and close to water points, where manure can be easily recovered. In the Zimbabwe case, only kraal manure was included in the nutrient calculation. The direct fertilization during stubble grazing should also have been taken into account.

The monetary value of manure depends on its quantity, but also on the quality in terms of nutrient content. In Zimbabwe, the nutrient composition of kraal manure was used in model calculations, according to data of Mugwira and Shumba (1986). The quality in terms of N and P was relatively low, subject to improvement though decrease of leaching and volatilization losses.

A nutrient loss factor for different soil types was added to the model according to suggestions of P. Driessen (pers. comm.). However, research on the recovery of N (50 %) P (30%) and K (50 %) are based on broadcast fertilizer trials. Recovery of nutrients by plants fixed in organic matter may be somewhat higher than of nutrients in mineral form. After mineralization, e.g. due to heavy insolation, they may get lost just as mineral fertilizers.

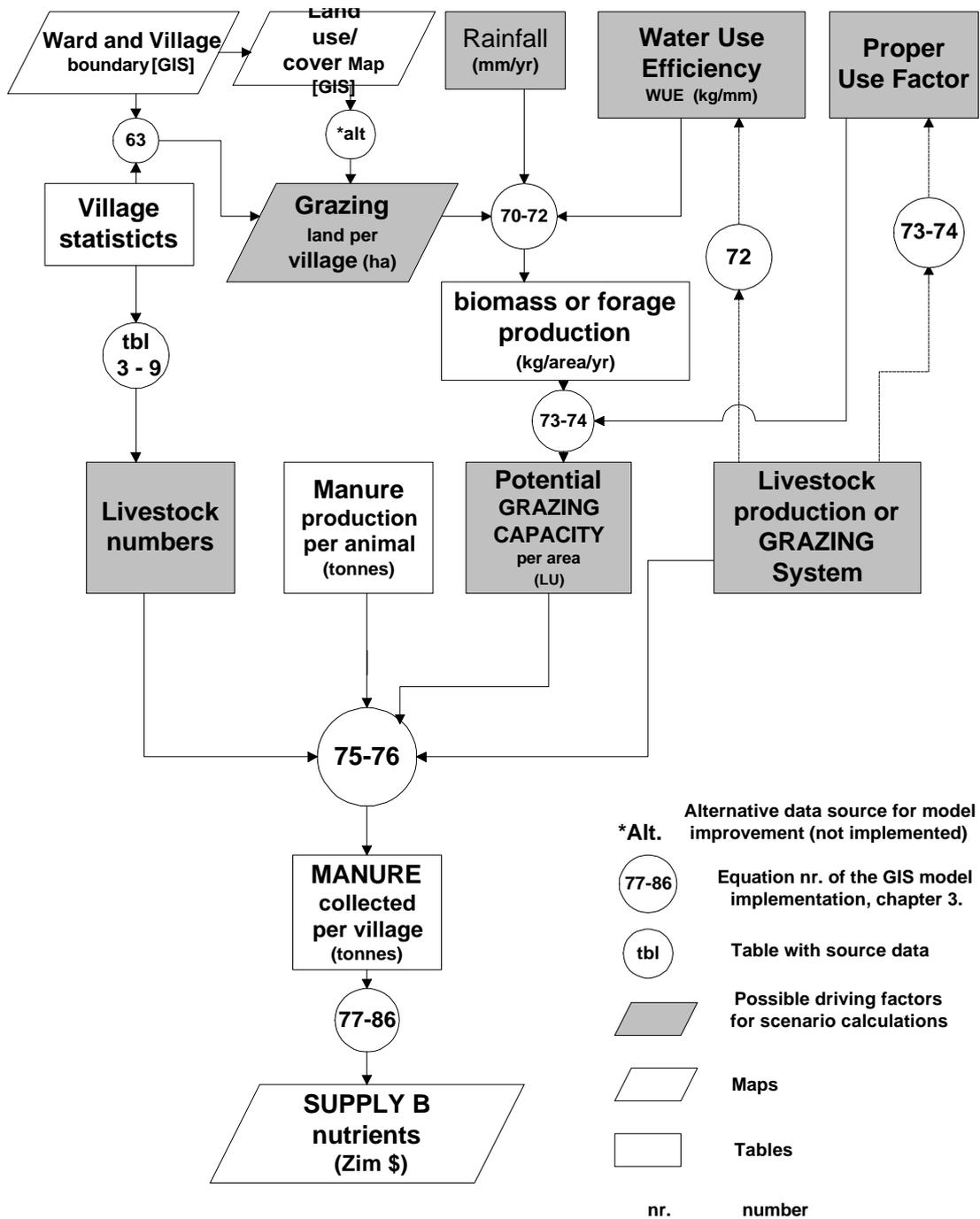


Fig. 5 The Manure sub model ("SUPPLY B")

Fig. 5. The manure submodel (supply B), which indicates the total amount of nutrients expressed in (Zimb.) dollars, optionally estimated from the variable livestock carrying capacity of village rangelands or directly from given animal statistics

Based on the proportion of nutrients in the manure, the manure quantities and the monetary value of nutrients derived from the fertilizer composition, the monetary value of manure is calculated per area in the model. This makes the subsequent evaluation of the relative importance of actual or alternative potential nutrient source and the comparison with total requirements easy.

4.4 Analysis of the gap between nutrient demand and supply

In this final sub-model, the nutrient supply from fertilizers (supply A) and from manure (supply B) is added and expressed as percentage of total demand. In principle, other supply sub-models could be created, e.g. to take into green manure though the use of leguminous species, alley cropping with perennials or agro-forestry systems.

Some key questions to be discussed are the following:

4.4.1 Is nutrient extraction from rangelands sustainable?

Uncontrolled use of forage and compost made from annual biomass species, or brought in from fallow and rangeland areas is considered to jeopardize for the sustainability of the rangeland subsystem (this was found by the authors e.g. in Madagascar, Burkina faso and India). Sustainable use of manure in the rangelands is supposed to be guaranteed, if the grazing capacity and the proper use factor is not exceeded, and if destructive practices are avoided. A certain percentage of woody species within the rangeland is considered to promote pumping of nutrients from deeper soil horizons to the top soil. and contributes to up to 25 % of the cattle diet (Le Houerou, 198.). Micro-organisms associated with the many leguminous species and some perennial grasses add nitrogen to the soil. Surface roughness in wooded rangeland areas favours atmospheric deposition of N and mineral sediment through wind action. Therefore moderate amounts of manure and plant biomass can be transferred from well managed rangelands to fields in a sustainable way .

4.4.2 What, if the present systems are unsustainable ?

If the zero scenario, based on current / average situation indicates a lack of sustainability (availability lower than nutrient requirements) the responsible factors and relevant management options have to be found. The GIS model usually gives different outputs for different types of areas. Therefore one question will be: what explains the difference between non-sustainable and sustainable areas. Looking back into the data base used by the model may explain the main differences between areas.

If differences are too much dictated by the given situation, management options for change should be sought. Those management options should be selected per area through an interactive process of (participatory) land use planning,

- which options have a significant impact on sustainability
- which options are economically feasible
- which options are socially acceptable

If e.g. rangeland areas are already marginal, it is less advisable to improve range land quality, but one might focus on agro-forestry systems including forage species.

5. Model Implementation

5.1 Method of model implementation

For simplicity, and for users without GIS facilities, a spread sheet version was prepared first, containing the main functionalities of the model. In a second step, a GIS version was prepared.. In ILWIS 1.4, a DOS based package, a batch program was written, including many explanations about the calculations. In a third step, parameters of the basic batch program were modified according to scenario calculations and saved separately for documentation.

In the future, a Windows based package may be used for further development of the model, map calculations as for tabular manipulations. If possible, there should be facilities for integrated remote sensing image processing functions (needed for a NDVI- biomass submodel), otherwise this may be kept separate.

5.2 Some results from the Zimbabwe scenario calculations

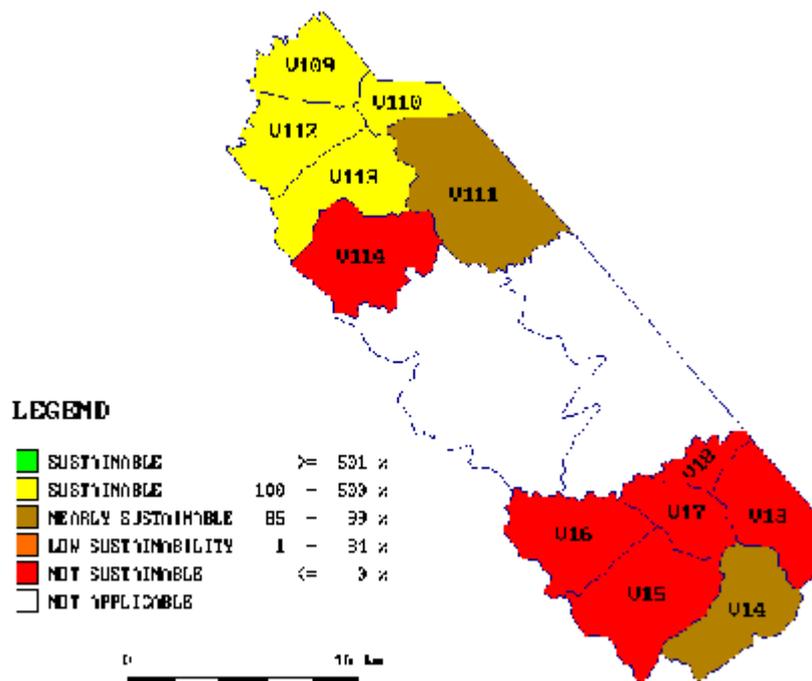


Fig. 6 The current sustainability of land use in the communal lands with production data of the very favourable rainfall situation of 1995/1996

A selected number of scenario calculations were done to explore the potential of the model:

Scenario calculation (1) examines the situation with respect to current sustainability of land use in the communal lands. The results turned out to be negative for two thirds of the

villages, even with production data of the very favourable rainfall situation of 1995/1996; see fig. 6). In average production years, land use is sustainable in none of the villages.

Scenario calculation (2) evaluating risks (effect of 50 % crop losses, e.g. due to drought or grass hoppers) only worsens the situation.

Scenario (3) evaluating the impact of improving farm gate producer prices of cash crops by 10 %, 50 % and 90 % shows that an increase in farm gate prices under normal rainfall situations would improve the situation for most areas as compared to scenario (1)

Scenario (4) calculates the minimum cash crop percentage required to meet the crop nutrient demand of all fields, with and without manure contribution. An area of between 2.7 to 7 times the current crop area would be required to generate enough cash for fertilization. This economy of scale cannot be achieved within the highly populated and marginal land of the communal areas. The impact of available manure in this scenario is negligible.

Scenario (5) estimates the potential impact of rangeland management, through increase of biomass production resulting from increase of the Water Use Efficiency (WUE) and of the proper use factor. This calculation shows that rangeland improvement will not have significant effects in high rainfall years. In normal rainfall years however, sustainability can be achieved to an extent similar to the situation of a good rainfall year. Therefore the results are identical to fig. 6). Varying the water use efficiency and the proper use factor causes an increase of the number of villages with sustainable land use from 1 (for WUE = 1 kg/mm and PUF = 20%) to 4 villages (for WUE = 3.5 and PUF = 30 %) and 6 villages (for WUE = 5 kg/mm and 45 %). In villages with few rangeland resources the potential impact of rangeland improvement is negligible.

Scenario (6) shows the potential impact of further population growth, based on growth rates of 2.5 % or 3%. Obviously, due to decrease of agricultural income per household, the situation will worsen, depending on the success of efforts of containment of demographic growth. The impact at short term (within 5 years) is not important, but will worsen the situation, if longer time spans are taken into account.

6. Conclusions and Recommendations for Further Research

Due to the integrative approach to model design, the first version of the model, hereby baptized as "SUSGIS" (SUStainable land use modeling using GIS) has shown to be capable to supply answers to some relevant management questions for regional to local land use planning.

Modeling the ecological and economic sustainability of an agro-pastoral land use system was found to go together well and could be applied by anybody with practical work experience and knowledge of general agronomy.

After preparation of the basic data sets and modification of the basic (batch) program, scenario outputs can be generated in map format automatically . The user-friendliness of the system may be increased by using a spreadsheet version, where GIS cannot yet be implemented easily, or by development of a windows version in a well known (mainstream) GIS package.

Availability of data sets, which are often a problem for conventional simulation models was found to be a lesser problem, if for implementation of the model, a choice of alternative data sources and model shortcuts is offered. On a case to case basis, those data sources should

be selected that were most reliable and suitable. Spatially distributed (map and image) input data are preferred for model applications, because they allow to differentiate suitable management solutions for land use planning, taking into account the specific resource availability of the management units (e.g. village territories).

For the Zimbabwe case, it is recommended to validate and evaluate the model results through repetition, sensitivity analysis and further scenario calculations, preferably by somebody with local research or work experience¹. A planned ITC fieldwork in Zimbabwe may provide further opportunities for model improvement

Further extension of the model is proposed through co-operation with interested parties, and modified to suit different areas:

- for the further elaboration of a pastoral (manure) sub-model
- for the elaboration of an agro-forestry sub-model
- for the elaboration of a socio-economic sub model, based on different household characteristics and options

7. Acknowledgements

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¹ P.S Some aspects to be investigated or improved in the Zimbabwe casestudy: The final scenario calculations of Bogere (1997) should be validated. Scenario 3 results are doubtful. The merit of the study is mainly in the detailed model design of the model. From scenario 5, a different conclusion for the relative importance of range land management could be drawn. Results could also be slightly pessimistic, because manure was considered to be available from kraals only, and because low animal numbers were used related to the recent drought. Direct fertilization of fields through stubble grazing, and (very limited) use of other nutrient sources would have improved the balance.

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