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Land Use Planning for Sustainable Agricultural Development

B O T S W A N A

LAND RESOURCES AND PRODUCTION SYSTEMS IN AGRICULTURAL LAND USE PLANNING IN BOTSWANA

by

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1. INTRODUCTION

The prosperity of Botswana largely depends on its natural resources. As to the agricultural sector, poor utilization of land resources has until now resulted in low crop yields, poor livestock offtake rates, low rural household incomes and widespread degradation of soils and rangeland.

Acknowledging these problems, the Botswana Government has recently adopted a series of policies to ensure that land resources are used in a sustainable manner. The Agricultural Policy Paper of 1991 stresses the need for land evaluation and environmental impact studies to be integrated in land use planning procedures. To this respect a technical cooperation project was established with the Food and Agricultural Organization (FAO) of the United Nations, titled *"Land Resource Assessment for Agricultural Land Use Planning"*. The project aimed at developing new methodologies for land evaluation and land use planning in Botswana and the present paper discusses some of its results.

It is planned that during the next five years (1992-1996) a follow-up project will be operational within the Ministry of Agriculture, titled *"Land Use Planning for Sustainable Agricultural Development"*. This project will further strengthen the Ministry's capability in planning the use and management of land for agricultural purposes. It is hoped that, through this follow-up project, the ideas presented in this paper will be implemented in future procedures for agricultural land use planning.

The paper presents an overview of the data sets and methodologies to be used in agricultural land use planning in Botswana. A new approach to land evaluation is discussed, on the one hand based on modelling the physical performance of a production system[1)] on a certain land unit, on the other on evaluating its economic success. The concept of a production system is examined, together with the data sets required for carrying out the physical and economic evaluation. It is demonstrated that modelling the performance of production systems should also include an assessment of risks, given the highly erratic nature of rainfall in Botswana. Physical modelling would also allow for a more accurate assessment of the environmental impact of a particular production system on a certain unit of land.

Having dealt with the land evaluation aspects, the paper subsequently proposes a conceptual framework for land use planning, focussing on the rural household level, where decisions are made as to which particular combination of production systems is selected. It is proposed that land use planners should evaluate each relevant combination of production systems, in order to assess its viability and desirability within the context of the objectives of the planning exercise.

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1) A production system is defined as *"a particular series of activities carried out to produce a defined set of commodities or benefits"* (see section 3.2 and 3.3 of this paper)

LAND RESOURCES AND PRODUCTION SYSTEMS IN AGRICULTURAL LAND USE PLANNING IN BOTSWANA [1]

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ABSTRACT

In Botswana agricultural land use planners are in the fortunate position of having access to a relatively well developed set of computerized land resource data bases with national coverage. Amongst others, they include the Botswana Soil and Vegetation data base, Meteorological data base, Ground Water Resource data base and the National Roads data base. Also a nationwide Wild Life Resource data base is currently being set up, and various local and regional data sets are available in the fields of rangeland assessment and the inventory of forest and veld products.

A number of studies have been carried out over the past 15 years, in order to estimate the suitability of land for agricultural use. Most of these studies aimed at one particular major land use (e.g. rainfed arable farming, extensive grazing) and were frequently restricted to one single region. What these studies had in common was that they applied a rather straightforward methodology. Land was rated into qualitative suitability classes by matching a limited set of physical parameters with their corresponding land use requirements. No attempts were made to estimate the production potential of land in quantitative terms and no methodology was available to carry out risk assessments or to evaluate the economics of a certain land use.

It is argued in this paper that for the purpose of agricultural land use planning the evaluation of different land use options should culminate in a comparison of rural household incomes generated by these land use options. To this end a farming systems, or rather household systems, approach is presented in which both land related and non-land related production systems are evaluated. The production system forms the centrepiece of the evaluation procedure, minutely describing the products to be produced and the inputs applied for each management operation. Attached to the Production Systems data base is a Costs and Prices data base, allowing for a final cost-benefit analysis once the amount of product produced is known.

The approach suggested heavily relies on physical modelling, since quantitative production figures are a prerequisite for assessing the benefits part of the rural household income. It will be demonstrated that modelling indeed is a feasible option in the Botswana situation, as the quality and amount of land resources data available is sufficient, at least for evaluating arable production systems. Such simulation models, like the Crop Yield Simulation and Land Assessment Model for Botswana (CYSLAMB), should include a risk assessment as well, in order to estimate in what percentage of years a certain income will be met, given the highly erratic nature of rainfall in Botswana.

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[1] This paper presents the views of the author which do not necessarily reflect those of FAO nor those of the Government of Botswana.

2. THE STATUS OF AGRICULTURAL LAND USE PLANNING IN BOTSWANA

2.1 Institutions

Agricultural land use planning in Botswana is mainly devolved to the Administrative Districts. Within each of these 10 Districts, the District Land Use Planning Unit (DLUPU) is the core group of planners. It consists of technical officers representing the various institutions involved in land use planning, including the District Administration, the District Council, the Land Boards and the Ministry of Agriculture. The DLUPU is assigned technical responsibility for designing a District Land Use Plan and advising the Tribal Land Boards on land use issues.

Closely related to planning and advising on agricultural land use is the agricultural extension service. Botswana is divided into 6 Agricultural Regions, headed by a Regional Agricultural Officer (RAO) from the Ministry of Agriculture. Each of the Agricultural Regions is sub-divided into several Agricultural Districts (not to be confused with the Administrative Districts). The District Agricultural Officers (DAO's) are responsible for the coordination of the extension programmes within these districts. The practical implementation of extension services to individual farmers is carried out by Agricultural Demonstrators (AD's).

2.2 Land evaluation and land use planning

Land use planning aims at selecting those combinations of land and land use that will best achieve the specified goals (FAO, 1989). These goals can be social, economical, political or related to conservation. They might deal with improving productivity, solving existing or preventing future land use conflicts, or with the introduction of new forms of land use. All these objectives, or combinations of objectives, can be formulated at the National, the District, the village or the individual household level.

Whatever the planning objectives, however, the methodology applied should first of all focus on the physical evaluation of land, in order to identify which land use options are physically relevant to the objectives formulated. Ideally, the terms used to express the performance of different land uses (the land evaluation results) should be mutually compatible, so as to be able to make objective comparisons between the various alternatives.

Until now land evaluation in Botswana has not been well integrated within the land use planning procedures. Various ad hoc methods have been used to estimate the capability or suitability of land for a limited number of major land uses (e.g. rainfed arable farming, extensive grazing, conservation). Most of these studies were restricted to a limited area (e.g. Siderius, 1970; Venema, 1980; De Wit and Moganane, 1990), although some methodologies were applied nationwide (e.g. Field, 1977; Sims, 1981; Rhebergen, 1988).

What these studies had in common was that they applied a rather straightforward methodology. Land was rated into classes according to a qualitative appraisal of its capability (based on Klingebiel and Montgomery, 1961) or suitability (based on FAO, 1976) for sustaining a certain major land use. No attempt has so far been made to incorporate crop and land husbandry practices into the evaluation and no comprehensive methodology was available to compare the productivity of land between major land uses. The latter approach would require a quantitative estimation of the production potential of land under a certain product management type, for which both the theoretical framework and required data sets were missing.

With these land evaluation results land use planners in Botswana have mainly carried out broad land zonation studies. The outcome of these studies have not always been satisfactory. As to smallholder arable farming a common observation amongst land use planners is that, given the prevailing socio-economic conditions, the current land use patterns and management practices already reflect the optimum use of land. It can safely be assumed that traditional farmers are their own land use planners and that throughout the ages they have become experts in managing their land resources. At best land evaluation in the way it has been applied confirmed these observations and the legitimate question raised is "Why, then, do we need land evaluation at all?".

As to commercial arable farming, the applied land evaluation methodologies did not cater for an in depth analysis of crop and land management practices. A good example is the rather disappointing performance of the newly established commercial farming enterprises at the Southern and Central Pandamatenga Plains in the North-East of the country. While having a high production potential, the management problems typical of these heavy clay soils were underestimated in the final implementation of the development plan (Arup Atkins, 1989).

One of the major issues in all land zonation studies is solving present land use conflicts or preventing future ones from arising. The demands for arable land, grazing, forestry, conservation, tourism, commercial and citizen hunting and the collection of veld products are always greater than the land resources available. In this field, land evaluation has until now been of particularly little use for land use planners in Botswana because of its incapacity to objectively compare the outputs of these conflicting land uses. Land might, for instance, be equally suitable for both arable farming and grazing, but which of the two is the most appropriate?

Instead of Land Evaluation, one could in these circumstances apply the methodology of Land Capability Classification (Klingebiel and Montgomery, 1961). This methodology handles the issue of land competition by scaling the conflicting major land uses in order of their relative intensity (e.g. Siderius, 1970; Venema, 1980). For instance, land units capable of sustaining arable farming without major environmental degradation risks would indeed be zoned as arable land, until the need for this form of land use is fulfilled and the remaining land units of this type are assigned to land use forms of lower priority. Land that is less capable of sustaining arable farming would be zoned as grazing, unless the predicted environmental impact would not allow so, and e.g. wildlife conservation becomes the more appropriate use.

Land Capability Classification, however, is a rather crude tool that does not permit any fine-tuning of land use. Land Suitability Assessment (FAO, 1976), on the other hand, does permit greater detail, but until now did not offer a satisfactory solution for deciding on land use conflicts (see above).

It can be concluded that land use planners need a methodology that allows for a quantitative and objective comparison between various land use options. With such a methodology the land use planner should be able to model the physical and socio-economic impact of all different land use scenarios. As a result, the decision making process becomes more transparent, making completely clear how and why decisions have been made and where interventions have taken place.

2.3 Agricultural extension

The agricultural extension programmes in Botswana are based on the findings and recommendations derived from crop, tillage, fertilizer and plant protection trials, carried out by the Department of Agricultural Research. In addition, a number of special programmes have been implemented over the years, of which the Arable Land Development Programme (ALDEP) and the Accelerated Rainfed Arable Programme (ARAP) were the most prominent. ALDEP aims at solving major production constraints amongst smallholders by offering government assistance for various farm investments (implements, fencing material, draught power). ARAP is now discontinued, but has offered a variety of services, aimed at improving current farm management practices and increasing the total area of productive land.

The Agricultural Demonstrators (ADs) are responsible for disseminating the recommendations from Agricultural Research to the individual farmers. In addition, they are active in the organization of farmer groups which could more effectively address common problems (e.g. the availability of draught power, the acquisition of inputs and the marketing of products). Another activity is the sensitization of farmers for the ALDEP schemes.

Although the ARAP and ALDEP schemes have received a reasonable good response in terms of the number of grants and subsidies supplied, the follow-up extension activities have been considerably less successful and the overall productivity of arable lands is steadily declining throughout the country.

The conclusion can be drawn that other physical or socio-economic constraints exist, which have until now not been addressed by the extension workers and land use planners. Of course, agricultural production in Botswana is limited by low and erratic rainfall and poor soil conditions, resulting not only in low crop yields but also in poor livestock offtake rates. However, historical records, field trials and simulation models (see chapter **4.**) demonstrate a much higher potential than the actual production figures nowadays met. Proper crop and land husbandry practices, like those advocated by ALDEP, indeed seem to be the key to success. But in a changing society, farmers in Botswana might need some extra incentives to effectuate these improved management practices and to make agriculture still a viable option within the context of their present social and economic perspectives. In other words, extension workers and land use planners should also focus on the socio-economics of rural households, in addition to the physical aspects of land use.

3. THE NEW APPROACH TO LAND EVALUATION: MODELLING PRODUCTION SYSTEMS

3.1 Why modelling?

As discussed in the previous chapter, land evaluation until now resulted in a qualitative assessment of the capability or suitability of land to sustain a certain land use. A clear disadvantage to this approach is the difficulty to compare land uses that produce different commodities. If, for instance, a land unit is equally suitable for traditional sorghum as well as for mechanized cotton production, which of the two land uses would be most the most successful? How would a local community, or even the National economy, benefit from photographic safari companies in a mixed production system[1] with wildlife conservation, as compared to the same land area being used for extensive grazing? These are questions that are highly relevant to land use planning in Botswana but had to be left unanswered until now.

By modelling the physical performance of such production systems one could predict its outputs in quantitative terms. Once the production is estimated (say in kilograms grain per hectare) and the commodity price and production costs are known, the gross margin (in Pula per hectare) of that particular production system could be calculated. This would be equally possible for crop and animal production systems, as well as for wildlife and veld products utilization systems, hence providing a common denominator for objective comparison.

Also very important are the risks inherent in rain dependent agricultural land uses. Given the highly erratic nature of rainfall in Botswana, the statistical probability of suffering a crop failure or loosing livestock as a result of a drought period is significant. Some crops are less vulnerable to dry spells than others and on certain land units they might still produce an acceptable yield. With appropriate management farmers could minimize risks and cattle owners could maintain an acceptable income even through bad rainfall years.

An assessment of risks can be conveniently done by modelling the performance of a production system using historical rainfall data over a wide range of years. Within this range of years (typically 20 or more) the statistical variation in yearly rainfall distribution is assumed to be sufficiently covered, so that the outcome of the analysis is representative for any long term period. From the array of yearly production figures that results from this analysis, one could calculate the median (achieved in more than half the years) and the first and third quartiles (achieved in at least 75% and 25% of the years, respectively). Another approach would be to calculate in what percentage of years the production exceeds a certain threshold value. Not only would the land evaluation results become more meaningful for land use planners (they do not predict an average production but give the probabilities of achieving certain production levels), the statistical approach would also allow for simulating the impact of certain management operations on production security. The latter aspect of modelling would be of great value, in particular for agricultural extension.

Another aspect of modelling worth mentioning is its potential to assess the environmental impact of a particular production system over a large number of years. The depletion of nutrients, the regeneration of a vegetation type or the loss of topsoil can be calculated by iteration, feeding the model with the results of the previous year. The resulting environmental impact assessment can be

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1) A production system is defined as *"a particular series of activities carried out to produce a defined set of commodities or benefits"* (see section 3.2 and 3.3 of this paper)

considered an output of the production system (in addition to the estimated production of commodities or other benefits) and taken account of in the actual land use planning.

3.2 Why production systems?

Land Evaluation (FAO, 1976, 1983, 1984, 1985 and 1989) has until now used the concept of a Land Utilization Type (LUT) to describe the interaction between land and men. A particular LUT is defined through its "key attributes", which is a set of technical specifications that affect the requirements or management specifications of the land use. Describing key attributes, however, is a rather static approach, in which no provisions are made to bring in the timing of the various inputs and management requirements. This is insufficient when it comes to quantitative analysis in relation to social factors, economics or environmental impact.

What we need to know, for instance, is when the farmer is able to plant, when exactly he carries out weed control operations and how long it would take him to harvest the produce. This is the kind of information that can be fed into a crop growth simulation model, which subsequently estimates in daily, weekly or 10 days intervals how such interventions affect the performance of the crop. The same information can be used to estimate the production costs or to analyze the timing of inputs in relation to other, possibly interfering, activities of the household or its neighbours.

To this end, the concept of a Production System was launched, defined as: *"a particular series of activities carried out to produce a defined set of commodities or benefits"*. At this point it is important to note that a production system is not necessarily related to land. The series of activities aiming at producing a certain output can as well describe undertakings in the spheres of home industry, labour supply, contracting, and so on. Typically, a rural household employs more than one production system at a time, of which some are related to land and some others are not. This imposes restrictions on the timing of the various inputs (most importantly labour), since all resources available to that household should be shared amongst the competing production systems. If the agricultural land use planning and extension is to focus on the socio-economics of rural households (see section **2.3**), then also the non-land related production systems should be taken account of.

In the new approach to land evaluation advocated in this paper, the concept of a production system replaces that of a LUT and the latter term is not used anymore. However, the old concept of key attributes can still be applied when carrying out qualitative land suitability appraisals. In addition to a detailed description of the series of activities that typifies a particular production system, also a summary of key attributes is given, thereby assuring compatibility with the term LUT.

3.3 Describing a production system

A production system is described at three different levels. Attached to this description is a list of costs and prices. All this information is best stored in a computerized format and to this end the LRAALUP[1)] project has developed the Botswana Production Systems Data base (BPSD).

BPSD is a dBASE III plus compatible computer program that stores, retrieves and analyzes the attributes of production systems. The attributes themselves are stored in four related data bases: *the*

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1) *"Land Resource Assessment for Agricultural Land Use Planning"*, TCP/BOT/0053, FAO and Ministry of Agriculture, Gaborone, Botswana.

Production Systems proper, the Product Management Types, the Management Operations and the Costs and Prices data base.

The production systems proper

At the highest level *Production Systems* (e.g. "Traditional Sorghum") are described by a specific combination of *Products* and a *Product Management Type* (see ***Table 1***). Also a summary description of the production system is given, together with its *Key Attributes* (see section **3.2**).

The combination of *Products* is defined in terms of a *first level output* (e.g. Sorghum, Cattle, Handicraft) and one or more *secondary level outputs* (e.g. grain + stover, live animal + draught power + milk, baskets). The first secondary level output represents the main product, whereas the others are optional and represent economically relevant by-products.

Also defined are the first level *variety* (e.g. Sorghum-Segaolane, Cattle-Tswana, Handicraft-Basketry), *target quantity* and *unit of measurement* (e.g. 25,000 plants/ha, 8 head/ha, 2 pieces/day). The units of measurement for the secondary level outputs should be defined separately (e.g. kg/ha, beasts/ha, liter/ha).

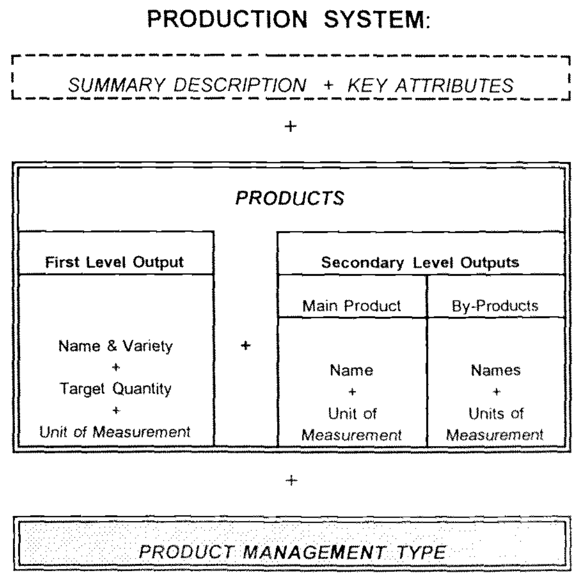

Table 1: *Defining a production system.*

The product management types

The *Product Management Types* (e.g. "Traditional Sorghum - Improved Tillage and Weeding") are defined at the next level. They represent a discrete sequence of *Management Operations* and their *Timing* (see ***Table 2***). An arbitrary *Starting Date* (month-day) should be defined, at which the sequence of operations is assumed to commence (e.g. 09-01).

If the timing of an individual operation is fixed, then its onset is indicated on an *absolute time scale* (number of days from the *starting date*; using numbers larger than 365 allows for defining a multiple-year production system).

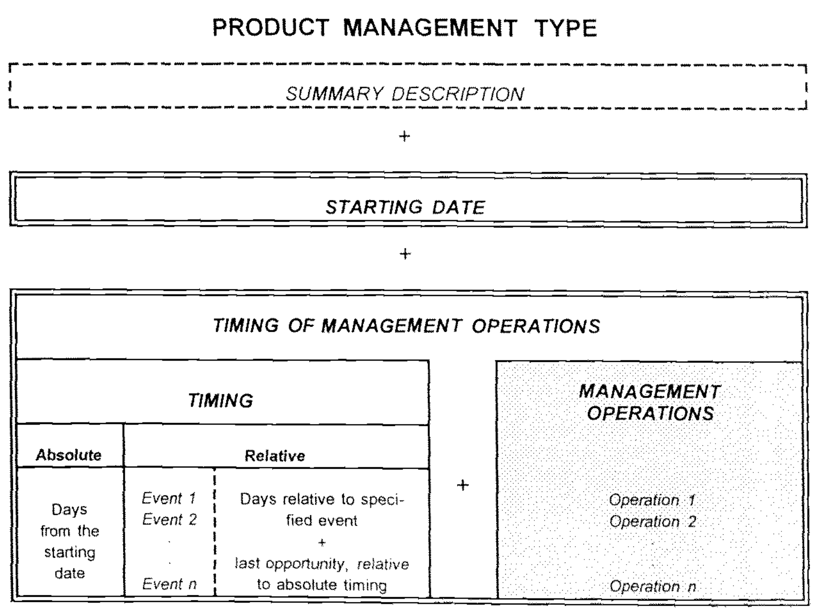

Table 2: *Defining a product management type.*

If, on the other hand, the timing of an operation is dependent on a certain event, then its onset is indicated on a *relative time scale* (± the number of days from the start of a certain event).

Relative time scales can be defined by indicating *the particular event* that makes up the origin of the time scale (e.g. the first significant rainfall of the season, the first planting opportunity, the harvest). The absolute starting date of such an event (the origin of the time scale) has to be calculated outside the BPSD program.

In case of relative timing, the absolute time scale should indicate after how many days from the *starting date* the operation is allowed to take place (e.g. after absolute day 365, if the operation is to take place in the second year of a multiple-year production system). Also the *last opportunity* should be defined, i.e. the number of days after which the operation is not allowed to take place anymore (e.g. in the case of second year planting, not after 170 days from absolute day 365, because it will be too late in the season).

The management operations

At the third and last level, the specific *Management Operations* (e.g. "Traditional Sorghum - Improved Tillage and Weeding - Early Ploughing") are defined by describing the inputs (*Power Source, Tools & Machinery, Material Inputs* and *Labour Inputs*) in terms of the attributes to each of these inputs (*Class, Type, Capacity, Unit of Measurement, Ownership/Source* and *Numbers applied*). An example of such a management operation can be found in ***Table 3***.

MANAGEMENT OPERATION: *Early Ploughing*

INPUTS: / ATTRIBUTES:	Power Source	Tools & Machinery	Material Inputs	Labour Inputs
Class	*Tractor*	*Plough*	*Fuel*	*Tractor Operator*
Type	*2×4 Wheel, 60 hp*	*3-disc*	*Diesel*	*Medium Skilled*
Capacity	2.5	2.5	15	2.5
Unit of Measurement	*hrs/ha*	*hrs/ha*	*liter/hr*	*hrs/ha*
Ownership/Source	*Hired*	*Hired*	*Purchased*	*Hired*
Numbers applied	*1*	*1*		*1*

Table 3: *Example of the definition of a management operation.*

The costs and prices

Attached to the definition of production systems, is a *Costs & Prices data base*. For any *Date of Observation*, the current *Costs* can be recorded for each combination of *Inputs* and *Attributes* (see ***Table 4***). Similarly, the current *Prices* can be recorded for each combination of a commodity produced and its quality class (see ***Table 5***).

By doing so, a simple cost-benefit analysis can be made of the performance of a production system on a certain land unit. The amount and quality of the product being produced is estimated outside BPSD by means of production simulation models (such as CYSLAMB[1]).

[1] *Crop Yield Simulation and Land Assessment Model for Botswana"*, discussed in chapter **4.** of this paper.

PRODUCTION COSTS:

	INPUTS: / ATTRIBUTES:	Power Source	Tools & Machinery	Material Inputs	Labour Inputs
	Class	*Tractor*	*Plough*	*Fuel*	*Tractor Operator*
	Type	*2×4 Wheel, 60 hp*	*3-disc*	*Diesel*	*Medium Skilled*
	Ownership/Source	*Hired*	*Hired*	*Purchased*	*Hired*
DATE:	UNIT OF PRICE:	***Pula/hr***	***Pula/hr***	***Pula/liter***	***Pula/hr***
91-01-01		**30.00**	**5.50**	**0.65**	**2.30**
92-01-01		**33.50**	**6.00**	**0.69**	**2.50**

Table 4: *Example of production costs in the Costs and Prices data base.*

PRODUCT PRICES:

DATE	1st Level Output	Variety:	2nd Level Output	Quality	Unit of Price	Price
91-01-01	*Sorghum*	*Segaolane*	*Grain*	***Class B***	***Pula/kg***	0.23
91-01-01	*Cattle*	*Tswana*	*Live Animal*	***Grade 1***	***Pula/kg***	1.88
91-01-01	*Cattle*	*Tswana*	*Live Animal*	***Grade 2***	***Pula/kg***	1.46
91-01-01	*Cattle*	*Tswana*	*Sour Milk*	***n.a.***	***Pula/liter***	1.00
91-01-01	*Donkeys*	*unknown*	*Draught Power*	***Good***	***Pula/beast/hr***	1.35
91-01-01	*Handicraft*	*Basketry*	*Baskets*	***High***	***Pula/gram***	.20

Table 5: *Example of product prices in the Costs and Prices data base.*

4. THE CROP YIELD SIMULATION AND LAND ASSESSMENT MODEL FOR BOTSWANA

The Crop Yield Simulation and Land Assessment Model for Botswana (CYSLAMB) aims at predicting the production capability of land units for a specified *crop-based production system*. Other land evaluation models relevant to Botswana would deal with *Animal Production* and with *Wildlife* and *Forest and Veld Products Utilization* (see ***Figure 1***). Of this series of methodologies, CYSLAMB is currently the only model that is operational[1].

Whereas the results from the crop production model are fully quantitative and include a statistical

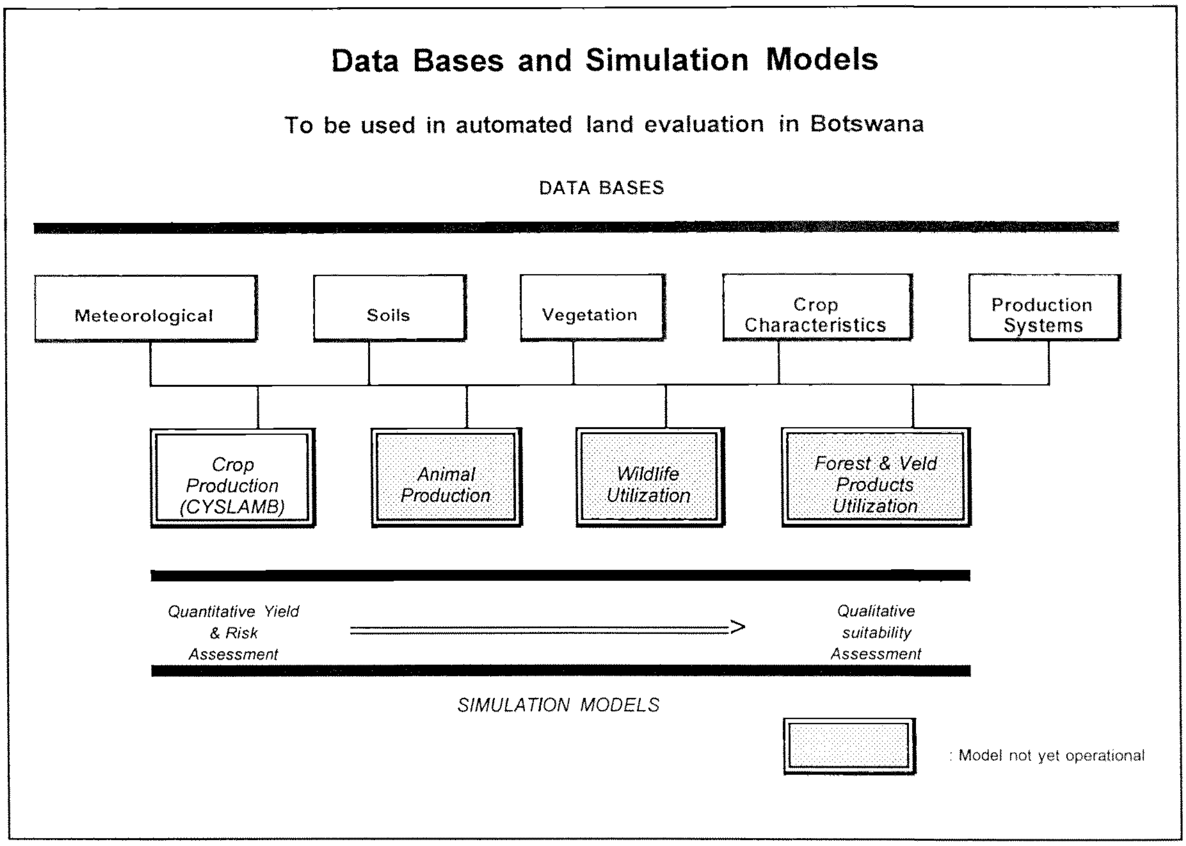

Figure 1: *Schematic representation of the data bases and various simulation models, to be used in automatic land evaluation in Botswana.*

analysis of the probabilities of achieving certain yield levels, the other simulation models may be more qualitative, due to the greater complexity of the production systems and the incomplete knowledge of the physiological processes involved.

CYSLAMB is fully computerized, automatically extracting its parameters from the *Meteorological, Soils, Vegetation, Crop Characteristics* and *Production Systems data bases* (see ***Figure 1***). The theoretical background of the simulation model is discussed in De Wit (1992) and in De Wit, Tersteeg

1) The development of additional land assessment models is an ongoing activity of the *"Land Use Planning for Sustainable Agricultural Development"* (LUPSAD) project, BOT/091/001, FAO/UNDP/Ministry of Agriculture, Gaborone.

and Radcliffe (1992). In the next sections of this paper some general characteristics of the computer program are discussed, together with the data set required to run the program. In addition, some examples of evaluation results are given for a Sorghum-based production system.

4.1 The CYSLAMB computer program

The CYSLAMB computer program consists of a number of separate modules, each having a discrete function within the overall simulation of the crop performance. Presently these modules include:

a) model for selecting a synoptic meteo station;
b) model for selecting a rainfall station;
c) model for selecting a range of cropping seasons;
d) model for selecting a crop/variety and target plant density;
e) model for selecting a soil unit;
f) model for selecting a production system;
g) model for selecting a report type (comprehensive or summary) and mode (screen, printer or disk file); subsequently the model reads into memory the meteorological synoptic data and the characteristics of the crop, soil and production system as selected in modules **a)** and **d)** through **f)**;
h) model for calculating the potential net biomass production;
i) model for calculating the yield reduction due to moisture stress, reading the decadal rainfall figures for the station and range of seasons selected in modules **b)** and c);
j) model for calculating the yield reduction due to excessive moisture;
k) model for calculating the yield reduction due to a deficiency of available Phosphorus in the soil;
l) model for calculating the yield reduction due to salinity, sodicity (Na-toxicity) and alkalinity;
m) model for calculating the predicted net biomass production and marketable yield, taking into account the yield reductions calculated in modules i) through l); in addition multi-year statistics are calculated in terms of the minimum, 1st quartile, median, 3rd quartile and maximum yield;
n) model for preparing the output of calculation results, according to the report type and mode, selected in module **g)**.

In addition to the modules mentioned above, one main module starts-up the program and calls all the other program modules. Before doing so, the main module presents the user with a menu from which different tasks can be invoked:

N Normal operation	(run one single evaluation)
C Create a command file	(create a list of evaluation runs)
R Run a command file	(run a list of consecutive evaluations)
E Edit	(edit databases, tables, command files)
V View/Print	(view or print databases, tables, command files and reports)

Selecting option ***N*** *Normal operation*, guides the user through all the selection steps and subsequently evaluates the performance of the selected crop for the selected land unit, range of seasons and production system. After producing the report, the user is back at the main menu, from which he can terminate the program or again select a menu option.

Options **C** *Create a command file* and ***R*** *Run a command file* allow the user to construct and run a list of consecutive evaluations (command file). Each record in the list represents a combination of a land unit, a range of seasons, a crop, a plant density and a production system. By using this command file facility, long evaluation sessions can be automated and standardized. A command file is created by repetitively guiding the user through modules **a)** up to **f)**, thereby recording the selections made. When such a command file is run, the program reads these selections (module **g)**), evaluates the crop performance and stores summary evaluation results in a disk file for each consecutive record.

Main menu options ***E** Edit* and ***V** View/Print* facilitate editing and inspection of the program's data bases (the meteorological synoptic data base and the rainfall, crop, soil and production systems data bases). These edit, view and print facilities are also accessible from the individual selection modules. In addition, these options also allow editing and viewing/printing of rating tables, command files (see menu option **C**) and the program's screen colors. Report files, stored on disk during previous evaluation runs, can be viewed or printed as well.

It is thought that the CYSLAMB computer program, as described above, represents a highly versatile and flexible evaluation tool. Its modular design makes it easy to replace current program modules with improved versions and to add new evaluation modules to the existing framework. The edit facilities allow for the construction of the individual data bases, but it is also possible to import information from already established data bases by building a simple ASCII interface. Using command files facilitates the evaluation of large data sets, allowing the computer program to run overnight and hence increase productivity. Reports are stored in plain ASCII files, which can easily be imported in commercial program packages for further data analysis.

4.2 The data set required for CYSLAMB

CYSLAMB automatically extracts the required parameters from the various data bases. These data bases can be constructed from within the program or by importing the information from already established data bases. The required data are:

METEOROLOGICAL DATA		
a) Latitude of the meteo station		*(°,′,″)*
b) Decadal effective rainfall for each year of observation	$= \sum_{1}^{10}$ *(daily rainfall > ETO)*	*(mm.decade^{-1})*
c) Average decadal		
* *Daily sunshine hours*		*(hrs.day^{-1})*
* *Maximum temperature*		*(°Celsius)*
* *Minimum temperature*		*(°Celsius)*
* *Relative humidity*		*(%)*
* *Rainfall frequency*		*(decade^{-1})*
* *ET_0 (Penman)*		*(mm.decade^{-1})*
CROP CHARACTERISTICS		
a) Harvest Index	$= F(HI_{max}, HI_{fact}$, *plant weight*)	*(kg.kg^{-1})*
b) Leaf Area Index	$= F(LAI_{max}, LAI_{fact1}, LAI_{fact2}$, *plant density*)	*(m^2.m^{-2})*
c) Moisture content produce		*(%)*
d) Maximum effective rooting depth		*(m)*
e) Length of crop development stages		*(days)*
f) Crop coefficients		*(mm.mm^{-1})*
g) Length of crop yield response periods		*(days)*
h) Crop yield response factors		*(kg.kg^{-1})*
i) Roots Development	$= F(RD_{min}, RD_{fact}$, *plant density*)	*(m.day^{-1})*
j) Roots as fraction of total biomass		*(kg.kg^{-1})*
k) Water logging sensitivity		*(class)*
l) Salinity sensitivity	$= F(EC_{min}, EC_{fact})$	*(kg.kg^{-1})*
m) Sodicity sensitivity	$= F(ESP_{min}, ESP_{fact})$	*(kg.kg^{-1})*
n) Alkalinity sensitivity		*(class)*
o) Phosphate response	$= F(P_{min}, P_{fact1}, P_{fact2})$	*(kg.kg^{-1})*

SOIL CHARACTERISTICS

a) Soil textural class	*(class)*
b) Soil drainage class	*(class)*
c) Soil depth	*(m)*
d) Available water holding capacity	*($mm.m^{-1}$)*
e) Weighted average pH over soil depth	*(pH)*
f) Available Phosphate in first 25 cm	*(ppm)*
g) Weighted average EC over soil depth	*($mS.cm^{-1}$)*
h) Weighted average ESP over soil depth	*(%)*

WEED CHARACTERISTICS

a) Evapotranspiration index (k_{c1}) at maximum ground coverage	*($mm.mm^{-1}$)*
b) Number of decades to reach maximum ground coverage	*(decades)*
c) Maximum ground coverage	*($m^2.m^{-2}$)*

PRODUCTION SYSTEM CHARACTERISTICS

a) Name and variety of crop	
b) First possible planting decade	*(decade)*
c) Last possible planting decade	*(decade)*
d) Number of planting opportunities to be taken	*(number)*
e) Minimum rainfall required for planting	*($mm.decade^{-1}$)*
f) Minimum available moisture in topsoil required for planting	*($mm.depth^{-1}$)*
g) Weed burden before planting	*(%)*
h) Weed burden after planting	*(%)*
i) Number of days after planting when weeding takes place	*(days)*

This data set is quite an extended one. Indeed, agricultural land use planners in Botswana are in the fortunate position of having access to large number of relatively well developed computerized data bases with national coverage. The Botswana Meteorological data base contains approximately 300 rainfall stations, of which an estimated 100 stations also have synoptic data recorded. The number of stations with more than 20 complete years of both daily rainfall figures and synoptic observations amounts 40.

The Botswana Soil and Vegetation data base currently has 3400 point observations, each providing a complete description of the physiography and vegetation of the site, as well as the soil horizons and resulting soil classification. Of these 3400 observations an estimated 2000 also include soil chemical and mechanical analyses.

Collecting and validating crop characteristics is a specialist task which requires sound knowledge of the theoretical background of the simulation model. At present, the LRAALUP/LUPSAD project has validated 5 rainfed crops for Botswana conditions: *Sorghum*, *Maize*, *Millet*, *Cowpea* and *Groundnut* (all locally adapted varieties), whereas the characteristics for an additional 30 crops are available for irrigated conditions.

The Production System data base has already been discussed in chapter **3.** of this paper. The data collection has started only recently and it will not be before 1993 until a fair amount of well described production systems is available for analysis. For running CYSLAMB, however, a much simpler set of characteristics is required, which can be stored straight away in the internal data base of the simulation program.

4.3 Some examples of a CYSLAMB evaluation

As an example, the evaluation results for a *Eutric Regosol* (soil unit code "RGe", FAO, 1988) in the *Francistown* area are discussed. The crop evaluated is *Sorghum*, with a density of *50,000 plants per hectare*. The production system is such, that the farmer is *not ready to plant before DEC1* (the first decade of December), and *not able or willing to plant after FEB2*. It is assumed that the farmer plants the land as soon as *the available moisture in the topsoil (0-50 cm) exceeds the amount of 30 mm* and, in addition, *the rainfall in that particular decade exceeded 30 mm* as well. Furthermore, the weed population on the land is assumed to be controlled effectively (*no competition from weeds*).

Example 1

In ***Figure 2*** an example is given of a *comprehensive* evaluation report for two cropping seasons (*1977/78 and 1978/79*). For each of these two seasons the model tried to identify *only one planting opportunity*.

In the top part of the CYSLAMB report the most important characteristics are summarized of the land (meteo station and soil unit) and of the production system. Next, the complete water balance is printed, starting at the 1st decade of September 1977. The model identified a planting opportunity at the second decade of December of that year. Further discussion of the water balance is beyond the scope of this paper.

C R Y S I M - R E S U L T S

Page 1

Synoptic station	: FRANCI	Soil unit	: RGe
Rainfall station	: FRANCI	Soil textural class	: Coarse
Range of seasons	: 1977\78	Soil drainage class	: Well
Crop/variety	: SORGHUM	Max. effective rooting depth for SORGHUM	: 1.00 (m)
Plants per hectare	: 50000	Water holding capacity	: 80 (mm/m)
Production system	: NLSM_N_1	Available P (Bray-II)	: 7 (ppm)
First/last planting dec.	: DEC1/FEB2	Weighted average pH	: 5.9 (H2O)
Planting opportunities	: 1	Weighted average ECe	: 0.0 (mS/cm)
Planting occurs when top soil water storage	> 30 (mm)	Weighted average ESP	: 3%
and decade rainfall	> 30 (mm)	Pre-planting top soil monitoring depth	: 0.50 (m)
Weed burden before pl.	: 0% of max.	Weeds maximum evapotr.	: 0.70 * ETO
Weed burden after pl.	: 0% of max.	Weeds max. cover after	: 40 days
Weeding occurs after	: 30 days		

CROPPING SEASON : 1977/78 Date of outprint : 03-24-1992

WATER BALANCE:

DEC	ST.D (cm)	ST.IN (mm)	RAIN (mm)	BS (mm)	ETw (mm)	AV.M (mm)	DEPL (%)	ETa (mm)	ST (mm)	MBRZ (mm)	W.FR (cm)	SURPL (mm)	ETc (mm)	STRESS (%)
SEP1	50		0	0					0	0	0	0		
SEP2	50		8	8					0	0	0	0		
SEP3	50		39	8					31	0	49	0		
OCT1	50		0	8					23	0	49	0		
OCT2	50		9	8					24	0	49	0		
OCT3	50		0	10					14	0	49	0		
NOV1	50		0	11					3	0	49	0		
NOV2	50		15	11					7	0	49	0		
NOV3	50		41	14					28	6	60	0		
DEC1	50		8	19					19	4	60	0		
└→	0	-19							0	23	60			
DEC2	13	5	114			10	77	10	0	70	100	57	17	41
DEC3	33	16	47			26	77	17	9	54	100	37	17	0
JAN1	52	15	158			42	67	25	17	38	100	141	25	0
JAN2	71	15	31			57	59	38	19	23	100	6	39	3
JAN3	90	15	85			72	53	48	24	8	100	47	50	4
FEB1	100	8	6			38	53	29	9	0	100	0	53	45
FEB2	100	0	55			64	53	44	20	0	100	0	51	14
FEB3	100	0	6			26	53	19	7	0	100	0	51	63
MAR1	100	0	14			21	53	16	5	0	100	0	51	69
MAR2	100	0	0			5	53	4	1	0	100	0	47	91
MAR3	100	0	0			1	59	1	0	0	0	0	36	97
APR1	100	0	0			0	67	0	0	0	0	0	26	100

POTENTIAL AND MOISTURE LIMITED PRODUCTION (kg/ha) - Planting at: DEC2

POTENTIAL PRODUCTION:			MOISTURE LIMITED PRODUCTION: Crop periods based			MOISTURE LIMITED PRODUCTION: Total period based		
Net Biomass (kg/ha)	HI	Market Yield (kg/ha)	Net Biomass (kg/ha)	HI	Market Yield (kg/ha)	Net Biomass (kg/ha)	HI	Market Yield (kg/ha)
11550	0.37	4860	4150	0.30	1410	6790	0.34	2640

YIELD REDUCTION : (%)	YR1	YR1B	YR2	YR3	YR23	YR4	YR5	YR
	0	0	17	36	55	20	64	41

——— no further planting opportunities identified ———

Page 3

OVERALL YIELD FIGURES Date of outprint : 03-24-1992

YIELD REDUCTION, due to the soil
- nutrient status (av.P) : 18%
- salinity (ECe) : 0%
- sodicity (ESP) : 0%
- alkalinity (pH-H2O) : 0%

MOISTURE RELATED YIELD REDUCTION FIGURES AND OVERALL YIELDS

SEASON	DEC	P.NBP (kg/ha)	M.YR (%)	M.YR5 (%)	SURPL (index)	D.YR (%)	YIELD (kg/ha)	HI (%)	YIELD5 (kg/ha)	HI5 (%)
1977/78	DEC2	11550	41	64	48	0	2080	33	1070	28
1978/79	JAN2	11520	55	74	3	0	1480	30	630	22

Figure 2: *Example of a comprehensive CYSLAMB report, identifying 1 planting opportunity for each of 2 years.*

After completing the water balance for the 120 days that this particular crop takes to ripen, the CYSLAMB report makes a prediction of the *Potential* and *Moisture Limited Net Biomass Production*. Two different methods have been used to estimate the impact of moisture stress on the yield: the *crop periods based* and the *total period based*. At present, only the total period based method is validated for Botswana conditions (this subject is comprehensively discussed in De Wit, Tersteeg and Radcliffe, 1992).

Page 2 of the comprehensive CYSLAMB report would have shown the same information for the next cropping season (*1978/79*). To save space, however, this second page is left out and ***Figure 2*** continues with the *Overall Yield Figures*, as presented on *page 3* of the CYSLAMB report.

For each of the two cropping seasons considered, the previously calculated *Potential Net Biomass Production* (P.NBP) and *Moisture limited Yield Reduction* (M.YR) are repeated. Added to these figures are the *Drainage limited Yield Reduction* (D.YR) and the yield reductions due to the *Nutrient Status*, *Salinity*, *Sodicity* and *Alkalinity* of the soil.

The overall yield predictions are displayed under the headings *YIELD* and *YIELD5* (for the *total period based* and the *crop periods based method*, respectively). Using the total period based calculation method, the model predicts a yield of more than 2 tons of Sorghum grain in the first year (planting at decade *DEC2*) and slightly under 1½ ton in the second year (planting decade *JAN2*). The much lower yield figure predicted for the second year results from a more severe moisture stress and sub-optimal temperatures during the final decades of the cropping period, a feature common to late planting.

C R Y S I M - R E S U L T S

Page 1

Synoptic station	: FRANCI	Soil unit	: RGe
Rainfall station	: FRANCI	Soil textural class	: Coarse
Range of seasons	: 1922\88	Soil drainage class	: Well
Crop/variety	: SORGHUM	Max. effective rooting depth for SORGHUM	: 1.00 (m)
Plants per hectare	: 50000	Water holding capacity	: 80 (mm/m)
Production system	: NLSM_N_1	Available P (Bray-II)	: 7 (ppm)
First/last planting dec.	: DEC1/FEB2	Weighted average pH	: 5.9 (H2O)
Planting opportunities	: 1	Weighted average ECe	: 0.0 (mS/cm)
Planting occurs when top soil water storage	> 30 (mm)	Weighted average ESP	: 3%
and decade rainfall	> 30 (mm)	Pre-planting top soil monitoring depth	: 0.50 (m)
Weed burden before pl.	: 0% of max.	Weeds maximum evapotr.	: 0.70 * ETO
Weed burden after pl.	: 0% of max.		
Weeding occurs after	: 30 days	Weeds max. cover after	: 40 days

OVERALL YIELD FIGURES — Date of outprint : 03-24-1992

YIELD REDUCTION, due to the soil
- nutrient status (av.P) : 18%
- salinity (ECe) : 0%
- sodicity (ESP) : 0%
- alkalinity (pH-H2O) : 0%

MOISTURE RELATED YIELD REDUCTION FIGURES AND OVERALL YIELDS

SEASON	DEC	P.NBP (kg/ha)	M.YR (%)	M.YR5 (%)	SURPL (index)	D.YR (%)	YIELD (kg/ha)	HI (%)	YIELD5 (kg/ha)	HI5 (%)
1922/23	DEC3	11540	44	65	36	0	1950	32	1050	27
1923/24	JAN3	11500	53	78	8	0	1550	31	430	18
1924/25	DEC1	11560	38	51	57	0	2240	33	1640	31
1925/26	JAN1	11530	39	57	5	0	2160	33	1360	30
1926/27	DEC1	11560	51	64	0	0	1640	31	1060	27
1927/28	DEC1	11560	56	82	24	0	1410	30	260	14
1928/29	DEC2	11550	37	58	58	0	2260	33	1330	29
1929/30	JAN2	11520	29	41	21	0	2630	34	2080	33
1930/31	DEC2	11550	47	65	6	0	1810	32	1020	27
1931/32	DEC1	11560	22	28	18	0	2930	35	2660	34
1932/33	DEC1	11560	61	83	10	0	1200	29	230	13
1933/34	DEC2	11550	43	62	15	0	1990	32	1170	28
1934/35	DEC1	11560	49	64	0	0	1720	31	1080	28
1935/36	FEB1	11450	59	77	0	0	1290	29	500	20
1936/37	DEC2	11550	42	60	16	0	2050	33	1240	29
1937/38	VOID	-9	-9	-9	-9	-9	-9	-9	-9	-9
1939/40	JAN2	11520	46	63	11	0	1880	32	1090	28
1940/41	DEC3	11540	53	79	15	0	1550	31	400	18
1941/42	DEC2	11550	52	69	13	0	1610	31	830	25
1942/43	DEC1	11560	46	54	1	0	1880	32	1500	30
1943/44	JAN1	11530	49	75	31	0	1740	32	600	22
1944/45	FEB1	11450	52	80	5	0	1590	31	370	17
1945/46	JAN1	11530	54	79	57	0	1510	30	410	18
1946/47	VOID	-9	-9	-9	-9	-9	-9	-9	-9	-9

Page 2

SUMMARY YIELD STATISTICS

Market Yield	Minimum (kg/ha)	1st Quart (> kg/ha)	Median (> kg/ha)	3rd Quart (> kg/ha)	Maximum (kg/ha)
Total period based:	0	1310	1720	2020	3320
Crop periods based:	0	260	850	1240	3190

Figure 3: *Example of a summary CYSLAMB report, identifying 1 planting opportunity for each of 66 years.*

Example 2

In ***Figure 3*** an example is given of a *summary* CYSLAMB report for a long range of cropping seasons (*1922-88*). The land characteristics and production system are the same as in **Example 1**. The purpose of the current evaluation is to get an idea of the statistical performance of the production system on this particular unit of land.

In a summary report like this one, no moisture balances or moisture limited production figures are shown. Instead, only the *Overall Yield Figures* are given for each of the 66 cropping seasons.

The table, as displayed in ***Figure 3***, is cut off after the season 1946/47, in order to save space. Within the period displayed, however, there are two seasons in which no planting opportunity was identified (*1937/38 and 1946/47*). Over the remaining years (1947-88), an additional three seasons didn't have any planting opportunity.

At the bottom of ***Figure 3*** the resulting *Yield Statistics* are given. Over the total of 66 cropping seasons, the *absolute minimum yield* was 0, whereas the *absolute maximum yield* was 3320 kg Sorghum grain per hectare (*total period based calculation method*). The *Median yield* over this period amounted 1720 kg/ha, whereas in 75% of the years a yield of more than 1310 kg/ha was met (*1st Quartile*) and in 25% of the years the yield exceeded 2020 kg/ha (*3rd Quartile*). If we compare these statistical figures with the two yields predicted for the two cropping seasons in **Example 1**, than it becomes clear that the yield of 1977/78 corresponds with an exceptionally good year and that the one of 1978/79 represents a yield more commonly met.

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                         C R Y S I M  -  R E S U L T S
                                                                    Page  1
Synoptic station          : FRANCI      | Soil unit                  : RGe
Rainfall station          : FRANCI      | Soil textural class        : Coarse
Range of seasons          : 1922\88     | Soil drainage class        : Well
Crop/variety              : SORGHUM     | Max. effective rooting
Plants per hectare        :  50000      |     depth for SORGHUM      :  1.00    (m)
Production system         : NLSM_N_3    | Water holding capacity     :  80    (mm/m)
First/last planting dec.  : DEC1/FEB2   | Available P  (Bray-II)     :  7      (ppm)
Planting opportunities    :   3         | Weighted average pH        :  5.9    (H2O)
Planting occurs when                    | Weighted average ECe       :  0.0 (mS/cm)
 top soil water storage >  30     (mm)  | Weighted average ESP       :  3%
 and decade rainfall    >  30     (mm)  | Pre-planting top soil
Weed burden before pl.  :   0% of max.  |      monitoring depth      :  0.50    (m)
Weed burden after  pl.  :   0% of max.  | Weeds maximum evapotr.     :  0.70 * ET0
Weeding occurs after    :  30     days  | Weeds max. cover after     :  40     days

OVERALL YIELD FIGURES                                Date of outprint : 03-24-1992

YIELD REDUCTION, due to the soil    - nutrient status  (av.P)  :  18%
                                    - salinity           (ECe)  :   0%
                                    - sodicity           (ESP)  :   0%
                                    - alkalinity     (pH-H2O)   :   0%

MOISTURE RELATED YIELD REDUCTION FIGURES AND OVERALL YIELDS
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SEASON	DEC	P.NBP (kg/ha)	M.YR (%)	M.YR5 (%)	SURPL (index)	D.YR (%)	YIELD (kg/ha)	HI (%)	YIELD5 (kg/ha)	HI5 (%)
1922/23	DEC3	11540	44	65	36	0	1950	32	1050	27
1922/23	JAN2	11520	52	72	40	0	1580	31	720	24
1922/23	JAN3	11500	57	82	30	0	1350	30	260	14
1923/24	JAN3	11500	53	78	8	0	1550	31	430	18
1923/24	FEB1	11450	57	84	9	0	1370	30	180	10
1923/24	VOID	-9	-9	-9	-9	-9	-9	-9	-9	-9
1924/25	DEC1	11560	38	51	57	0	2240	33	1640	31
1924/25	DEC2	11550	34	49	43	0	2390	34	1720	31
1924/25	JAN2	11520	25	31	32	0	2800	35	2510	34
1925/26	JAN1	11530	39	57	5	0	2160	33	1360	30
1925/26	FEB2	11590	62	88	16	0	1180	28	20	2
1925/26	VOID	-9	-9	-9	-9	-9	-9	-9	-9	-9
1926/27	DEC1	11560	51	64	0	0	1640	31	1060	27

Page 4

SUMMARY YIELD STATISTICS

Market Yield	Minimum (kg/ha)	1st Quart (> kg/ha)	Median (> kg/ha)	3rd Quart (> kg/ha)	Maximum (kg/ha)
Total period based:	0	690	1113	1657	3233
Crop periods based:	0	177	447	800	3083

Figure 4: *Example of a summary CYSLAMB report, identifying 3 planting opportunities for each of 66 years.*

Example 3

In the previous two examples, the evaluation model tried to identify only one planting opportunity per cropping season. This approach is useful if one is only interested in the yield that can be achieved on each hectare planted. Taken the farm size into consideration, it is assumed that the farmer actually plants the total farm area at the first possible opportunity.

However, such a situation rarely ever occurs. In practice, the farm size is too big and the capacity and availability of draught and man power too limited to plant the whole farm area at once. Rather does the farmer split-up his efforts amongst a number of smaller areas, also for the sake of spreading risks.

In this example a farm is assumed to be *partitioned into three different areas*, each to be planted at a different planting opportunity. Such a partitioning represents the average smallholder in Botswana, given a farm size of around 6 ha and the capacity of a span of oxen to plough approximately 2 ha of coarse or medium textured soil in 2½ days.

In ***Figure 4*** the results of such an evaluation are presented. All land characteristics are the same as in the previous two examples. Also the production system is the same, except that it requires

3 planting opportunities to be identified. The effect of this requirement is clearly visible: already in the second cropping season (*1923/24*) no third planting opportunity occurred, leaving 1/3 of the farm unproductive in that particular year. The same happened in *1925/26* and several times more so during the years not displayed in ***Figure 4***, with sometimes only one single planting opportunity being identified.

If we now compare the *Summary Yield Statistics* with those of ***Figure 3***, **Example 2**, then the predicted yields are substantially lower. The statistical yield figures in ***Figure 4*** are based on the averages of three yields per year, thereby treating missed planting opportunities as zero yields. The figures, therefor, represent the yearly *on-farm production per hectare total farm area*. Another reason why the statistical yield figures in this example come out much lower than if only one planting opportunity was identified for each year, is that the average planting date has been pushed forward towards the end of the cropping season. On average, this results in less favourable climatic conditions (see also **Example 1**).

5. PUTTING IT ALL TOGETHER: A CONCEPTUAL FRAMEWORK FOR LAND USE PLANNING

In the previous chapters a new approach to *land evaluation* has been discussed, based on modelling production systems. An example of such a model is CYSLAMB, a computer program that simulates the physical performance of a particular *production system* on a certain *land unit*. The results of such modelling are expressed in *physical terms* (e.g. kg yield/ha), which can be converted into *economical figures* through a *cost-benefit analysis* of the production system.

The land evaluation procedures are represented in the bottom left corner of ***Figure 5***. However,

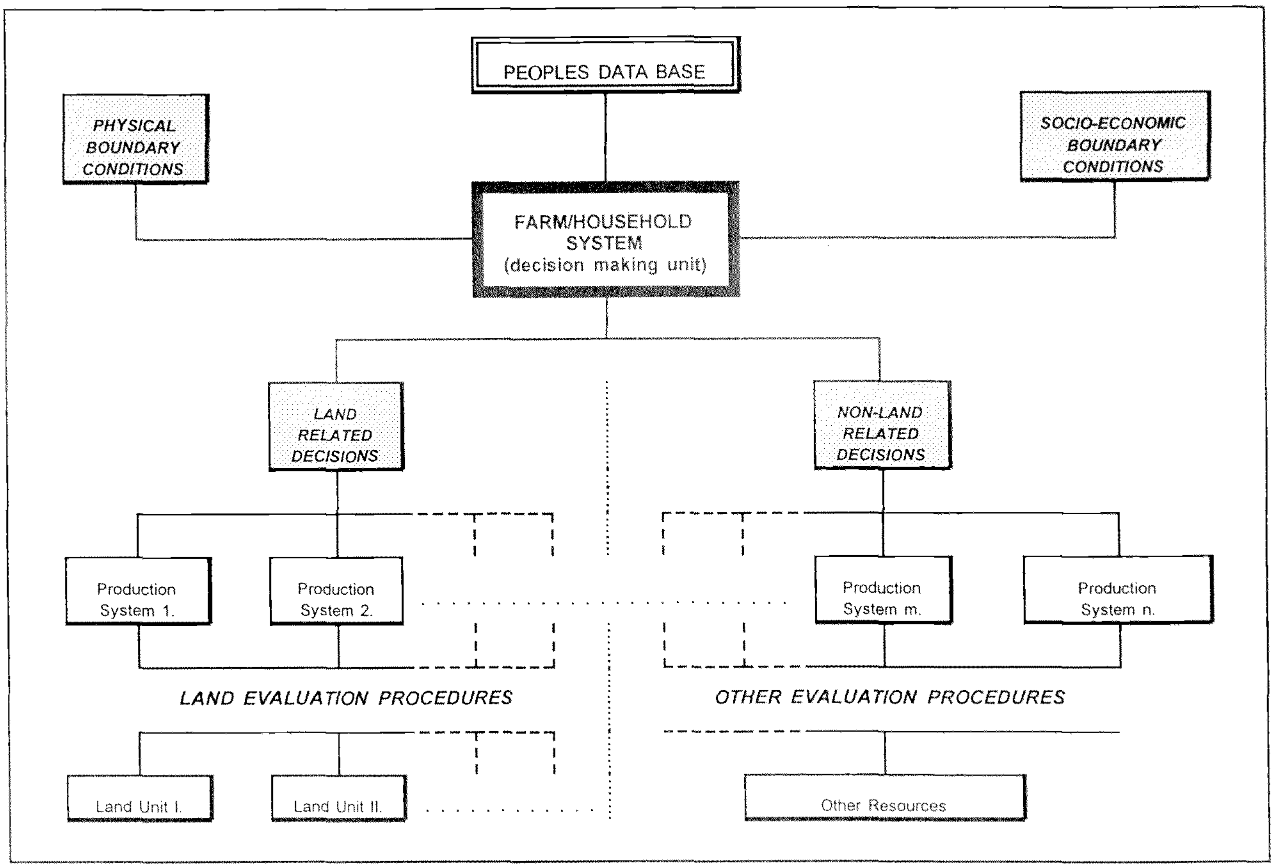

Figure 5: *Conceptual framework for evaluating combinations of production systems at the farm/household level.*

production systems are not exclusively related to land. *Non-land related activities* can be evaluated similarly, but instead of matching production system requirements with land characteristics, these *other evaluation procedures* should assess *other resources* relevant to these production systems. This concept is shown in the lower right-hand side of ***Figure 5***.

The evaluation results of the two groups of production systems (*land related* and *non-land related*) are mutually compatible and can be brought together at the *farm/household level* for further analysis. First of all it should be checked whether no conflicts occur in the *timing* of the various management operations, since all resources available to the household should be shared amongst all competing production systems. As a result of this, it might indeed be necessary to change one or more production systems and to re-evaluate the new scenario.

Next, the combination of evaluation results is to be subjected to an *environmental and socio-economic impact study*. Typically, a rural household unit employs a variety of production systems simultaneously, of which some are, and some are not related to land. A particular combination of production systems is selected according to the capabilities and ambitions of the household unit, in response to the anticipated *physical and socio-economic boundary conditions*. This is the *decision making process* that, in a free enterprise society, governs the choices between the various land use options available. By adding up the economic performance and environmental impact of all component production systems employed by the household, the land use planner would be able to assess the *viability and desirability* of the specific combination of production systems, taking into account the *objectives* of the planning exercise.

The *decision making process* at the farm/household level works out differently for different household units. Here the need for setting-up a *Peoples Data base* is felt (see ***Figure 5***). Such a data base should characterize rural households in terms of their *composition*, *capabilities* and *ambitions*. The most appropriate way of handling this information is by means of an *Expert System*, which allows the storage of decision patterns in *"if-then structures"*.

If, by means of such an expert system, the decision making process at the rural household level can be simulated, land use planners would have a powerful tool at their disposal to estimate how a change in socio-economic boundary conditions (e.g. commodity prices, subsidies, legislation) would affect the choices being made, and the income being generated, by the household unit. In macro-economic terms: by trying out a number of *development scenarios*, land use planners would be able to indicate what set of *government interventions* is most favourable in the context of the *development objectives* formulated.

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