THE AGRICULTURAL POTENTIAL OF SADC

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Various institutions wanting to invest in agricultural production or the agribusiness sector in the SADC region need information on the quality and location of agricultural resources. Generating agricultural resource information on a regional level provides the challenge of integrating vast amounts of information from the various countries, implying storing, retrieving and manipulating it to determine areas best suited to grow a particular crop; or various crops that can be grown in a particular area. A Geographical Information System (GIS) has been developed as part of a broader project to assess the agricultural potential of SADC countries from a physical-biological-climatological point of view. Crop suitability maps obtained from the GIS containing information on resource quality, combined with transport modelling to add information on transport cost, can be used by private sector institutions for location decisions and the public sector for planning the provision of physical and social infrastructure. Incorporating resource data of the whole region implies that the available data on the climate, topography and soils of most of the SADC countries is coarse which only allows analyses on a national and regional level.

1. INTRODUCTION

The Department of Agricultural Economics at the University of Stellenbosch is involved in research, as part of the Agrifutura Project, whose aim is to investigate the agricultural potential of the SADC region. The first two phases of the project have been funded by the Development Bank of Southern Africa, and have resulted in two major reports covering the socio-economic profile of the SADC member countries (Rwelamira and Kleynhans, 1996 and a spatial model, using a Geographic Information System (GIS), of the natural resources of the region (Agenbach *et al* forthcoming.)

The purpose in the third phase of the project is to use this natural resource inventory to investigate the optimal production and trade patterns for agricultural commodities in the region. Quite simply, we are aware that:

- The SADC region has a great diversity, and at the same time considerable similarities, in its natural and human resource endowment;

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- An important similarity is the dominance of agriculture and its contribution to national development;

- The performance of agriculture in the region has, however, not even remotely approached the real potential of the region, therefore leaving much scope for increased performance in the future.

The problem is that conventional economic analyses of the trade potential of the region have to use past trade flows as their data source. However, it is clear that the size and direction of future trade flows will largely depend on the extent to which this potential is unlocked.

The aim of phase three of the study is, therefore, to generate more accurate information on the socio-economic and physical-biological characteristics of the SADC region that can be used for the development of scenarios of technically and economically viable production and trade patterns. Such scenarios can then be used to answer questions about where, in what manner and what type of infrastructure, institutions and technology are required to bring the resources of the region into production.

2. BACKGROUND

2.1 DBSA-related studies on regional co-operation in Southern Africa

In 1993 the African Development Bank (ADB) published a collection of volumes as a final report of a study on Economic Integration in Southern Africa executed by the ADB with assistance from the Nordic Countries (ADB, 1993). This study investigated the potential for an integrated Southern Africa and in the process also discussed the agricultural sector. In this study it was emphasised that, inter alia, major expansions in areas under production and increases in level of technology applied would be necessary to meet the demands of the region. It was also stated quite clearly in the report that the then major producer of agricultural commodities and staples, South Africa, will experience a decline in the production of staples due to internal and international deregulation and a comparatively weak resource base for crop production (ADB, 1993:125).

In 1994 DBSA launched an investigation into the multisectoral linkages within the SADC region (Kritzinger van Niekerk, 1997), building on the findings of the ADB study. This study, which favoured the merits of a gradualist approach to regional integration, covered several sectors of the economy in an attempt to illustrate the interdependence between these sectors within the different countries of the region. It highlighted the important role of, *inter alia*, agriculture in intra-regional trade (Van Rooyen, 1997) and examined the potential for stronger linkages in the sector. It illustrated empirically that a vast potential for agricultural production expansion exists in the region and that the utilisation of this potential would lead to significantly different food production and distribution patterns. Furthermore, the analysis of the agricultural sector revealed the cross-sector linkages to trade, transport, water and irrigation in the region.

2.2 The interest of South African agricultural institutions in the region

Private sector investors in production

Private sector investors in production agriculture want to know which areas are suitable for the production of a particular crop, and which areas will be developed by means of country, regional or donor-funded development projects. For example, it is possible that specialised production companies may want to benefit from production nearer to growing (urban) markets in the region. They may also want to exploit seasonal differences with the Northern Hemisphere, or move to areas with lower labour cost or fewer environmental conservation restrictions. In any case, they will want to know *a priori* which crops are suitable in a given area, based on an assessment of suitability from a socio-political, locational and/or infrastructural point of view.

Investors in the agribusiness sector

The interests of input supply companies include looking for areas of concentrated production as an alternative to domestic markets, especially where they have a competitive advantage over existing (third country) suppliers. South African based fertiliser and petroleum products firms have been amongst the first to expand into the region for this purpose. The presence of competing companies will always determine their interest in a specific location of production. Processing companies such as millers and malting companies, on the other hand, could play a stronger role in initiating production in areas nearer to growing markets that are suitable from a physical-biological and location point of view (as has already been done e.g. by South African brewers and dairies). While suppliers of agribusiness services, such as finance, business consulting, and information services often have a more parochial outlook, new opportunities may induce them to look further north.

Public sector institutions

It is evident that a wide range of public sector institutions has an interest in the manner and pace at which the agricultural potential of the SADC region is exploited. Departments of Agriculture, for example, need to know about optimal production patterns of a particular crop in a regional context, if and how such patterns can serve food security enhancement more effectively and how it differs from production patterns that have evolved from national policies of food self-sufficiency. From a food security point of view it is also important to know if and how regional specialisation and trade can add to more stable production and savings on e.g. grain storage costs.

Departments of Trade and Industry are in turn interested in opportunities for value-adding and export, and therefore the best location of primary production, while agricultural research institutions will be interested in the demands on research and extension services if un- or under-utilised agricultural resources are used more efficiently. Matters such as co-operation in developing and transferring technology across national borders in order to use resources in an area with high physical potential will also be of importance.

Semi-state, regional and multilateral institutions such as the DBSA, the World Bank, Eskom and the ADB, which are involved primarily in the financing of infrastructural development, will need information on the income generating capacity of agriculture and agribusiness activities in an area that will be served by e.g. a particular road. Alternatively, information may be required on the location of areas with the highest agricultural production capacity and population pressure where infrastructural development can have a maximum impact in the region.

Donor institutions in the private voluntary sector

Grassroots NGOs from the local, national and international spheres would generally like to have more information on the location of areas of high agricultural potential, and more specifically about the agricultural potential of the areas in which they operate. They need to know which products can be produced for food production and/or income generation by a particular community, how far away markets for inputs and farm produce are, and what prospects are offered by the off-farm rural economy.

3. SOCIO – POLITICAL - INSTITUTIONAL CHARACTERISTICS OF SADC

Phase I of the SADC project provided a socio-economic description of the individual SADC countries and of the region in general. It compares SADC countries in terms of a wide variety of socio-economic and development parameters and tries to show similarities and imbalances in the region. The idea is to strengthen an awareness of the regional linkages and dependence among SADC countries. The fact that the first report is already in its third printing indicates the need for such a source of information. Not all the SADC countries were included in the first report since the work underlying the report was completed before Mauritius, the Democratic Republic of the Congo and the Seychelles joined SADC.

Table 1 below shows relevant socio-economic data for the countries in the SADC region. The data show that, while population growth rates remain high, they are expected to decline in all countries except Mozambique within the next generation. The most important result is the substantial decline in the proportion of the population below 15 years of age between now and 2025 (and the concomitant increase in the proportion of those over 65 years. This changed demographic pattern is expected to result in a rising demand for horticultural products and meat, and a relative decline in demand for field crops. Within the field crop group, the demand for wheat is expected to rise relative to the demand for maize. Given current production patterns, this means the region will become more reliant on wheat imports. Nevertheless, the region is characterised by widespread (rural) poverty, as evidenced by the low HDIs.

This expected increase in domestic demand for higher value foods creates a positive incentive for agricultural production in Southern Africa. In addition, there are a number of global factors that will stimulate demand for production in the region. This includes the counter-seasonal advantage that producers have in competing with farmers in the Northern Hemisphere, the rising cost of energy faced by farmers in the North, and the more stringent labour and environmental regulations with which they have to comply. Although farmers in Southern Africa will also have to comply with humane labour regulations, and will have to follow sustainable farming techniques, it is likely that their cost of compliance will be lower.

If the region is to exploit these opportunities to the fullest, production will have to shift to the areas most suited for the different crops and animal

Table 1: Selected socio-demographic and human development indicators in the SADC countries

	Angola	Botswana	Lesotho	Malawi	Mauritius	Mozambique	Namibia	RSA	Swaziland	Tanzania	Zambia	Zimbabwe
Population (millions) : 2000	13.1	1.83	2.2	12.6	1.2	19.4	2.0	47.17	1.0	35.9	10.7	13.2
2025	26.62	2.85	3.78	24.92	1.40	36.29	3.75	72.00	1.74	74.17	20.98	22.89
Population growth rate (%) 1990-95	2.94	2.92	2.47	3.31	3.00	2.83	3.18	2.36	3.20	3.36	3.50	2.97
2000-25	2.91	2.69	2.39	2.42	0.85	2.87	2.91	2.18	2.64	2.99	2.56	2.48
Crude birth rate (per 1000) 1990-95	51.3	38.4	34.4	54.5	18.1	45.1	42.5	31.3	37.2	48.1	46.4	40.6
Life expectancy at birth: 1996	46	51	58	43	71	45	56	65	57	50	44	56
Crude death rate (per 1000) 1990-95	19	9.0	10	22	7	18	11	9.4	10	15	18	11
Infant mortality (1000 live bir 1996	124	56	74	133	17	123	61	49	67	86	112	56
Annual urban population growth (%): 1992-2000	2.3	3.5	3.2	2.9	0.3	3.9	2.8	0.8	3.0	2.9	0.6	2.3
Urban population (%) 2000	36	33.0	27	16	42	41	43	53	36	28	45	36
Age structure (%): 1990												
< 15 years:	47.1	44.9	40.7	49.2	26.7	44.9	45.0	37.5	42.5	48.0	48.5	44.6
15-65 years	50.0	51.8	55.3	48.2	67.5	51.9	51.7	58.5	54.4	49.6	49.3	52.6
>65 years	2.9	3.3	3.9	2.6	5.8	3.3	3.4	4.0	3.1	2.5	2.2	2.8
2025												
<15 years	39.9	25.5	29.5	42.3	-	40.4	31.2	25.6	-	40.2	38.6	26.8
15-65 years	56.9	69.0	65.7	55.2	-	56.9	64.5	67.0	-	57.2	59.2	68.1
>65 years	3.2	5.5	4.8	2.5	-	2.7	4.3	7.4	-	2.6	2.2	5.1
School enrolment ratio for all levels (% age 6-23) 1994	31	71	56	67	61	25	-	-	72	34	48	68
Adult literacy rate: 1996	42	70	71	56	83	40	-	82	77	68	78	85
Science graduates												
(as % of total) 1988-90	45	3	5	23	26	21	-	-	196	20	10	12
Human Development Index: 1995	0.344	0.678	0.469	0.334	0.833	0.281	0.644	0.717	0.597	0.358	0.378	0.507

Sources: UNDP. 1994. *Human Develoment Report 1994 - 1998*. New York: Oxford University Press.
World Resources 1994-1995. 1994. New York: Oxford University Press.

products i.e. there will have to be a greater degree of specialisation in the sector. This creates a wide variety of opportunities cooperation, e.g. mutually beneficial exchange of technology; cross-border investment in agricultural production and in the agribusiness sector; and trade opportunities.

Given the need and opportunities for co-operation and trade in the region, the socio-economic profile study of the SADC countries was followed by an assessment of the physical potential of the agricultural resources of the SADC region to support the identification of possible future development programmes.

4. PHYSICAL-BIOLOGICAL CHARACTERISTICS OF SADC

Phase II of the SADC Agricultural Potential Assessment study resulted in the development of a capacity to store information on agricultural resources, and to generate information on the possible use of those resources for agricultural production. The vast amount of data was captured in a Geographic Information System (GIS) to be retrieved and manipulated to deliver information according to specific needs, e.g. to determine the quantity and location of various classes or qualities of arable land and areas suitable for a particular crop. The capacity of the GIS to select areas for specific purposes by manipulating the available data sets and to quantify the size of such areas indicates the superiority of the technique in storing and generating information for resource planning purposes. The GIS also allows easy upgrading of data sets to improve the accuracy of the instrument. The GIS was developed and is supported by a multidisciplinary group of agricultural scientists at the University of Stellenbosch.

4.1 Evolution of GIS

Over the past two decades, advances in digital technologies have addressed and solved limitations in the capturing, storage, retrieval, presentation and analysis of geographical data. The integration of descriptive (non-graphic) database information with digital geographical data has resulted in the *Geographical Information System* (GIS) or Spatial Information Systems. Although the term GIS is a product of the information era and generally refers to digital data, it also encompasses manual or analogue systems dating back to the earliest maps drawn on clay tablets (cf. Burrough, 1986: 1-12 and Aronoff. 1989:31-45 for an explanation of computer– assisted cartography and the principles of GIS).

Since the 1980's, the use of GIS has grown dramatically around the world. It is now commonplace for business, government and academia to use GIS for many diverse applications. Many of the earlier applications in Europe were aimed at building land registration systems and environmental databases. For example, Britain's largest GIS expenditure in the 1980s was for developing utility systems and for creating a comprehensive topographic database for the country. Canada developed a forestry application to plan the volume of timber cut and to identify access to the timber. Applications in China and Japan emphasised monitoring and modelling possible environmental changes. In the United States, a GIS of the US transportation network was developed (refer to ESRI, 1990: 1-8). The MARS project (Monitoring Agriculture with Remote Sensing Project) currently developed for Europe aims at the quantitative estimation of the acreage occupied by various crops in a given country or region; vegetation and crop state monitoring; timely crop yield forecasting of mean crop yields per country; and the rapid and timely estimation of the European Community's total production of the most important crops. An agricultural potential study based on a GIS for Kenya was developed by FAO and the International Institute for Applied Systems Analysis (IIASA) and linked to a multi-criteria optimisation model to determine optimal land use patterns in terms of given goals (FAO, 1995). The Institute for Soil, Climate and Water of the Agricultural Research Council of South Africa developed a land type GIS and can show applications on agricultural potential, run-off potential, climate zoning and infrastructure availability for South Africa.

According to Huxhold (1991:25), there are as many definitions of GIS as there are disciplines involved in using geographic information systems (e.g. geography, urban planning, engineering, environmental science and others). ESRI (1990: 1, 2) gives the following definition of GIS:

> *An organised collection of computer hardware, software, geographical data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information.*

4.2 Decision support

A purposefully designed GIS is invaluable in supplying timely and accurate information to managers and others responsible for decision-making. With adequate analytical and statistical modelling support, a GIS answers well to the following definition and characteristics of a decision support system (Grimshaw, 1994):

A decision support system (DSS) is a computer-based system that helps the decision-maker utilise data and models to solve structured problems.

The key characteristics of a decision support system are:

- It can incorporate both data and models;
- It has been designed to assist managers in semi-structured or unstructured tasks;
- It supports, rather than replaces, management judgement;
- The objective of a DSS is to improve the efficiency with which decisions are made.

For example, regional planners may need information about the location of areas in the SADC region that could potentially support the growing of certain basic crops. The growth potential of each crop is subject to certain constraints set by climate, topography and soil. In Phase II of the SADC project, a large volume of data layers covering soil, climate, topography and demography was obtained and integrated in the GIS. The capability of the GIS to conduct spatial queries over multiple related data layers proved crucial for identifying the potential of certain areas exhibiting certain topographical, climatological and soil characteristics to support these crops. Figure 1 explains how these related data layers represent some of the geographies of the real world.

4.3 The SADC agricultural GIS: software, data structure and hardware

The SADC Agricultural GIS aims to provide information on a regional basis to find, compare or assess areas of agricultural production with regard to their suitability in terms of certain criteria. This SADC GIS can assist with planning and optimisation in the region by highlighting the salient characteristics of a specific area, indicating the locations that answer to certain stated criteria, and compare areas in terms of stated criteria. The GIS can also be teamed with optimisation models for more advanced analyses.

The Geographical Information System (GIS) software used in this project was *PC ARC/INFO* version 3.4D, *UNIX ARC/INFO* version 7.0.2, *ARCVIEW* version 3.0 and *Spatial Analyst* [ESRI]. All data had to be in digital format. *ARC/INFO* employs two types of data structures, namely *grids* and *vector coverages*. Grids are used to approximate continuous or uniform spatial-related

Figure 1: Real world situation presented by the integration of various descriptive data layers

phenomena by means of a collection of discrete, equally sized cells. Each cell contains one or more descriptive database attributes. In this project grids were used to represent all climatic data. Vector coverages approximate point, linear or shape related features with points, lines or polygons. Examples of these are wells, roads and lakes. Like grids, each of these entities may contain one or more descriptive database attributes e.g. name of lake, type of road, owner of well etc. In this project, national borders, roads, cities and existing crop patterns are examples of vector coverages.

PC ARC/INFO and *ArcView* was installed on a Pentium 150Mhz IBM compatible personal computer with 32 Mb RAM and 7Gb hard disk space using Microsoft's *Windows 95* operating system. This PC was later upgraded to a 200Mhz MMX. *UNIX ARC/INFO* resided on a *SUN SPARC-20* generic workstation with 96Mb RAM and 15Gb hard disk space running *Solaris 2.3* on a *SUNOS* operating system.

4.4 Resource inventory of the SADC agricultural GIS

The resource data inventory describes the various data sets or coverages on matters that are relevant for crop production. These data sets are complemented by data sets describing the infrastructure, demography and political borders of the SADC region. At the time of data collection and analysis, the SADC region comprised the following eleven countries: Angola, Botswana, Lesotho, Malawi, Mozambique, South Africa, Tanzania, Namibia, Swaziland, Zambia and Zimbabwe. Mauritius, the Republic of Congo (Zaire) and Seychelles joined the community at a later stage, hence their exclusion from the project.

4.4.1 Climate of the SADC region

Tables 2, 3 and 4 summarise the climate data inventory of the available digital SADC data used for this project. (Geographic co-ordinate system, Clarke 1880 spheroid).

Table 2: Climatic grids for the SADC region (one for each month of January to December)

Data layer	Resolution	Units	Source
Mean minimum temperature	3′x3′ (≈ 5km)	°C x 10	ANU*
Mean maximum temperature	3′x3′ (≈ 5km)	°C x 10	ANU
Median precipitation	3′x3′ (≈ 5km)	mm	ANU
Mean evapotranspiration	3′x3′ (≈ 5km)	mm	ANU

Source: Australia National University

Table 3: Climatic grids for South Africa (one for each month of January to December)

Data layer	Resolution	Units	Source
Mean annual temperature	1′x1′ (≈ 1.87km)	°C	CCWR*
Mean minimum temperature	1′x1′ (≈ 1.87km)	°C	CCWR
Mean maximum temperature	1′x1′ (≈ 1.87km)	°C	CCWR
Median precipitation	1′x1′ (≈ 1.87km)	mm	CCWR

Source: Computing Centre for Water Research, Pietermaritzburg, South Africa.

Table 4: Summary of SADC climate data

Month	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Climate range	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Min Temp (deg C)	-9.3	24.8	-10.1	24.7	-9.1	24.5	-8.8	24.7	-8.5	23.1	-10.3	21.8	-11.1	20.8	-11.1	21	-11.8	22.2	-11.1	24.5	-10	24.7	-9	24.5
Max Temp	0	38.4	0	37.7	-0.4	36	-1.7	34.7	-3.6	33.5	-3.7	33.7	-4.5	33.5	-3.5	34	-1.8	35.7	-1.2	39	-2	38	-1.6	37.5
Mean Temp	-4.7	29.4	-5.1	29	-4.8	29.3	-5.3	-29	-5.8	28.1	-7	26.6	-7.8	26.3	-7.3	27	-6.8	27.9	-6.2	30.5	-6	30.4	-5.3	29.3
Precipitation (mm)	0	489	0	404	0	397	0	498	0	472	0	140	0	98	0	114	0	117	0	227	0	280	0	417
Evapotrans-piration (mm)	64	238	58	187	54	178	34	141	20	140	22	144	21	154	28	171	51	192	52	228	42	224	50	241

Source: Australia National University

The data sets above are based on approximately 50 years long-term monthly mean meteorological station data and surfaced with an advanced interpolation routine developed at the Australian National University by Michael Hutchinson.

Tables 5 and 6 summarise the topography and soils data inventory of the available digital SADC data used for this project.

Table 5: Elevation grid for SADC

Data layer	Resolution	Units
SADC elevation	0.5′x0.5′ (≈ 900m)	m above MSL

Source: SADC Regional Remote Sensing Project, Harare.

Table 6: Soil coverages for SADC

Data layer	Source map scale
SADC soils	1:1 million ONC's
South African soils	1:250 000

Source: SADC RRSP, Harare; ISCW, Pretoria.
ONC = Operational Navigational Charts

4.5 Data shortcomings

The quality and accuracy of GIS outputs depends strongly on the quality, accuracy and standardisation of its base information. In the construction of the SADC Agricultural GIS, the acquisition of digital environmental and soil data proved to be a challenge. Factors contributing to this difficulty included the unavailability of information, non-standardisation in terms of the classification of data, different approaches in terms of the digitisation of maps and different systems in terms of government administrative areas. Apart from the South African data, the broad information base of this project comprises a variety of data layers compiled by various institutions outside Africa. In compiling and integrating these data sets, it is inevitable that errors were introduced and that these errors are reflected in the analysis.

4.5.1 Soil

Considering the effort of different institutions each interpreting and digitising soil maps for single SADC countries, the overall integrated digital SADC soil coverage had surprisingly few obvious errors. A major error encountered with the soil data was discontinuities of soil polygons across national borders. Soil polygon boundary mismatches between neighbouring countries, and in some cases, dissimilar soil types across national boundaries (e.g. between Angola and Zambia) were responsible for obvious anomalies in the results. Human resource and time constraints limited the investigation of these base map interpreted errors. It is proposed that errors be clarified with the responsible institutions. The relatively small scale of the soil base maps (1:1 million) tends to generalise or absorb smaller details necessary at regional level. If or when available, soil maps captured from larger scale base maps should be incorporated for analysis at the regional level.

4.5.2 Climate

The accuracy of the relatively coarse resolution SADC climatic grid compares very well with the well-documented climatic grid of South Africa, except for under representation in the winter rainfall region of South Africa. The finer resolution South African climatic grid was used for analysis in this region. A formal statistical correlation of these two climatic grids should be a good indication of the accuracy of the climatic data for the rest of SADC.

4.5.3 Topography

The finer resolution elevation grid of South Africa (200m) provided better results in slope classifications than the relative coarse (900m) SADC elevation grid. Analysis in the rest of SADC involving slope could be improved substantially by using a finer elevation grid.

4.6 Quantity and location of arable land

The GIS has been used to combine basic data sets or coverages to indicate areas suitable for agricultural use. Each time the resulting map and quantities of land calculated must be seen in terms of the specified parameters used. The simplest combination of data on mean annual precipitation, soil depth and slope is done to show the relative size and location of arable areas. 'Arable' land is used as a very general indication of suitability for crop production and is defined as land with adequate soil depth to store sufficient water in areas with sufficient rainfall and which are flat enough to allow mechanical cultivation without too high a risk of water erosion. The location of arable areas in the SADC region is shown in Figure 2 and the quantity of arable land per SADC country is given in Table 7.

Table 7: Arable land in the various SADC countries ('000ha)

	TOTAL	Angola	Botswana	Malawi	Mozambique	South Africa	Tanzania	Zambia	Zimbabwe
Arable land in summer rainfall areas									
High class	**161 783**	65 895	0	3 445	30 858	-	29 645	29 805	2 135
Medium class	**82 179**	18 878	163	2 398	15 355	5 485	17 587	8 880	13 433
Low class	**54 293**	8 463	4 868	823	7 088	7 685	12 420	318	12 628
Arable land in winter rainfall areas									
High class						136			
Medium class						1 272			
Total arable land	**298 250**	93 235	5 030	6 665	53 300	14 578	59 653	39 003	28 195
Non-arable land	**296 436**	31 435	53 507	2 743	25 109	107 742	28 952	35 069	10 472
Total land area	**594 686**	124 670	58 537	9 408	78 409	122 320	88 604	74 071	38 667

Notes:

1. Arable land for Namibia, Lesotho and Swaziland could not be calculated with the GIS as no digitised soil map for these countries exist.
2. Parameters of arable land classes:

Summer rainfall area:

High class:	1000 mm ≤	soil depth;	800 mm ≤	mean annual precipitation;	2% ≥ slope
Medium class:	1000 mm >	soil depth ≥ 750 mm;	800 mm >	mean annual precipitation ≥ 650 mm;	6% ≥ slope
Low class:	750 mm >	soil depth ≥ 450 mm;	650 mm >	mean annual precipitation ≥ 500 mm;	12% ≥ slope

Winter rainfall area:

High class:	450 mm ≤	soil depth;	450 mm ≤	mean annual precipitation;	12% ≥ slope
Medium class:	450 mm >	soil depth;	450 mm >	mean annual precipitation ≥ 300 mm;	12% ≥ slope

Figure 2: Arable land map

The classification of areas in terms of various classes of arable land or non-arable land is refined by a classification in terms of a wider variety of land suitability classes, which takes into account the interdependence between precipitation and soil depth. An area with shallower soil but higher precipitation or deeper soil but lower precipitation can still be classified in a higher class than what the simple arable land classification will allow.

In the case of arable land and land sustainability classes, resource quality is expressed here in a general way for the region as a whole and per country. Resource quality can also be expressed more specifically in terms of crop potential by means of crop suitability maps. The crop sustainability maps are based on more specific requirements of a particular crop, e.g. soil acidity.

4.7 Agricultural potential expressed in terms of crop suitability maps

The term 'potential' is only used with reference to a particular crop as resources that are suitable for one crop maybe unsuitable for another. Using the concept 'potential' in general would therefore be senseless. The potential of any particular part of the earth's surface to maintain growth and production of any crop/plant depends on the suitability of the three essential components of land, *viz*. ***climate***, ***terrain*** and ***soil*** for different crops.

4.7.1 Potential assessment according to climate

Climatic influences on potential crop growth vary between different crops. Low temperatures adversely affect some crops while others, for example, need long hours of sunshine. The suitability of a specific climatic characteristic to support crop growth is presented by a symbol from the set S1 through N2 (c.f. Table 8). Each suitability class is calculated from the range of values it occupies in the climatic characteristic.

4.7.2 Potential assessment according to topography

The main topographical limitations on potential growth of crops are height above mean sea level (MSL) and slope. Due to the correlation between temperature and altitude, the former limitation is usually accounted for in the minimum temperature requirements. The steeper the slope, the stricter the limitations on potential growth. A slope grid was calculated from the digital elevation data set (Table 5) and classified according to slope requirements for individual crops using the requirements set fourth by Sys *et al*.

4.7.3 Potential assessment of soil

The soils data that were available for Botswana, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe consisted of sets of digitised soil association map data. The classification system that was used to compile these soil maps is defined in *Soil map of the world (scale 1: 5 000 000). Volume I: Legend.* 1974. FAO-UNESCO, Paris). This system is based on the identification of diagnostic soil horizons and soil properties. A range of *soil groups* is defined on the presence and/or absence of diagnostic soil horizons. Soil groups are subsequently subdivided into *soil units* primarily based on specified soil properties.

The digitised soil map for the countries listed above contained the following information on soil type bases:

- Area in km^2;
- Dominant soil unit with percentage coverage;
- Associated soil units (maximum of four) with percentage coverage; and
- Included soil units (maximum of four) with percentage coverage.

The suitability of a soil unit for the growth and production of crops/plants is a function of the individual soil type, as well as integrated chemical, physical and morphological properties and nature of that particular soil. In a very extensive discussion on the soil, terrain and climate requirements of a large range of crops, Sys *et. al*. (1993), made use of a large range of soil-terrain-climate parameters. The rating of the qualitative suitability of each property is shown in Table 9.

Table 8: Suitability classes of a soil unit based on soil, terrain and climate parameters

<table>
<tr><td colspan="2">S1</td><td>S2</td><td>S3</td><td>N1</td><td>N2</td></tr>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td colspan="2">4</td></tr>
<tr><td colspan="6">100%   95%   85%   60%   40%   25%   0%</td></tr>
</table>

The symbols used in this framework have the following meaning:
Suitability class:
S1 Very suitable
S2 Moderately suitable
S3 Marginally suitable
N1 Actually unsuitable but potentially suitable
N2 Unsuitable
Intensity of limitation:
0 No limitation
1 Slight limitation
2 Moderate limitation
3 Severe limitation
4 Very severe limitation
Suitability rating:
Expressed as a percentage

Eleven soil properties have been used by Sys *et al* (1993) to evaluate the suitability of soil as one of the components that determine land potential. Based on the definitions of diagnostic horizons and properties, a fairly good estimate of the limits of individual soil properties could be made for each defined soil unit.

4.8 Refinement of crop suitability maps

The objective of Phase III of the SADC Agricultural Potential Assessment Project is to upgrade the quality and reliability of the resource data generated in Phase II; to exploit the strengths of the GIS to develop production and trade scenarios based on transport modelling to generate information needed for infrastructure planning; to ensure that all the countries that recently joined the SADC be included in the system (based on the availability of appropriate information); and to formalise the SADC Agricultural GIS in a recognisable legal entity.

The development of crop suitability maps by determining crop requirements and linking it to the resource base revealed a serious lack of knowledge with regard to crop suitability in the SADC region. Crop requirements for the SADC region developed by institutions outside SADC can only be seen as a starting point and do not provide sufficiently accurate maps. Local crop modelling capacity in all the SADC countries will have to be mobilised to determine an acceptable methodology for integrating available crop modelling knowledge as a basis for future co-operation and to provide an accurate crop suitability map for a range of agricultural crops. To this end, a workshop took place in early November 1998 where agro-meteorologists and agronomists from all SADC countries were asked to test the accuracy of the existing crop suitability maps, and to recommend ways of improving them.

5. SPATIAL DISTRIBUTION OF SUITABLE RESOURCES FOR A PARTICULAR CROP: AN ECONOMIC PERSPECTIVE

5.1 Transport modelling

Transport modelling has been used to indicate the effect of trade liberalisation of maize among a limited number of SADC countries (cf. Nuppenau, 1993), and all the SADC countries (Van Looveren, 1998). Free trade in maize in the region can lead to cost savings on maize storage as part of national food security strategies. Both Nuppenau and Van Looveren showed optimal distribution patterns between net producing and net consuming areas based on current maize production patterns.

However, as stated earlier, these analyses make use of existing trade flows, and hence on existing production patterns. Therefore, Phase III of the SADC project will encompass transport modelling to determine scenarios of optimal maize production and distribution patterns in SADC based on maize production potential quantities per province according to the maize suitability map for the region. The GIS complements transport modelling by combining information on resource quality from a Ricardian perspective with the Von Thunen focus on location resulting in transport cost. By using crop production potential figures per hectare, based on resource quality and the hectares of suitable land per province (or even per magisterial district), one can generate information on the quantities that it is physically possible to supply for consumption in the region or for export. The results will provide information on transportation routes from main potential production areas to consumption areas and ports for export. This information can then be used for infrastructural planning.

The models developed by Nuppenau and Van Looveren concentrated on maize only, and had as objective function the minimisation of transport cost.

No product-product relationships were taken into account. In a study on optimal agricultural resource use in Kenya, for which optimal production patterns were determined by means of a linear programming model, based on production potential figures from a GIS, product-product relationships were also taken into account (FAO/IIASA 1994). However, the SADC project will probably also have to exclude these relationships due to resource and time constraints.

5.2 Combination with information on comparative economic advantage (CEA) analysis

Comparative economic advantage (CEA) analysis is the most common criterion used to evaluate economic efficiency in terms of social welfare gains from feasible alternative production options. It evaluates the economic efficiency of alternative productive uses of scarce land, labour, capital and water resources within a particular country or region in an attempt to capture the interaction between national resources, production technology, product demand and government interventions.

Hassan & D'Silva (1994) investigated the reasons for the importance of conducting CEA analysis within an agro-ecological framework. They concluded that agricultural production is primarily a biological process that is highly dependent on prevailing biophysical conditions. Agricultural suitability reveals the similarity in natural resource endowments and production potential, and hence complementarity or competitiveness in trade, between countries.

The Domestic Resource Cost (DRC) methodology provides an analytical tool for an empirical evaluation of economic efficiency among alternative enterprises. It is a commonly used criterion for measuring CEA. The DRC method generates several measures of the relative economic efficiency of production alternatives. It is used as an *ex ante* measure of comparative advantage to determine which among a set of alternative production activities is relatively efficient for a country or region in terms of contribution to national income.

An alternative measure of economic efficiency that is easier to interpret is the resource cost ratio (RCR). Resource cost ratios provide an explicit indication of the efficiency with which production alternatives use domestic resources to generate or save foreign exchange (Morris, 1990), thus serving as a relative indicator of the degree of efficiency. RCRs also lend themselves more readily to cross-country comparisons. The RCR is obtained when both the numerator and denominator in the above-mentioned formula are expressed in the same currency units.

The usefulness of CEA analysis is demonstrated in Table 9. By using GIS technology one can ascertain the potential for improving cultivation technology to improve yields. The effect of such technology changes on a crop's comparative advantage can be measured by using the RCR methodology. Improved production technology that improves a specific crop's yields will increase the opportunity cost of producing an alternative crop. The table shows, for example, that soybeans will have a comparative advantage over maize production in agro-ecological zone 6 in South Africa. The RCR for soybeans is less than one, indicating its superiority over maize. If, however, it is assumed that new technology improves maize yields by 0,5 tons per hectare, maize will have a comparative advantage over soybeans, *ceteris paribus*.

Table 9: The effect of production technology changes on the comparative advantage of maize

Description	Technology: Status quo		Technology: Improvement in maize	
	Maize (dryland)	Soybeans (dryland)	Maize (dryland)	Soybeans (dryland)
Yield (ton/ha)	2	1,4	2,5	1,4
Gross returns (R/t)	1114,82	1945,78	1393,53	1945,78
Tradable component (R/t)	524,62	1025,37	524,62	1025,37
Value added (R/t)	590,20	920,42	868,90	920,42
Cost of domestic resources (R/t)	100,89	175,66	100,89	175,66
Component of tradables (R/t)	540,99	699,17	141,12	350,99
Total cost of domestic resources (R/t)	641,88	874,83	641,88	1153,54
Resource cost ratio	**1,09**	**0,95**	**0,74**	**1,25**

Note: 0<RCR<1 indicates comparative advantage
Adapted from Jooste & Van Zyl (1997)

Welfare can be increased in the SADC region by free trade, allowing more optimal production and trade patterns based on resource quality and transport cost. Providing agricultural resource information on an integrated, regional basis can support scenario planning of the possible effects of various regional trade policies. Such scenario planning can provide guidelines for e.g. the provision of transport, infrastructure, irrigation development and the location of institutional support like agricultural research and extension services.

The SADC Agricultural GIS has been developed to integrate the agricultural resource information of the various SADC countries in order to facilitate regional planning. The GIS enables storing of digitised information on *inter alia* climate, topography and soils of SADC and the manipulation of the data in order to show the suitability of a particular area for the production of various crops. Otherwise, it can be used to locate area(s) which are suitable in terms of specified criteria, such as suitability for a certain crop and distance from a railway line.

The development of the GIS and the transport modelling of maize based on actual production are preparatory steps to develop transport modelling based on agricultural production potential. The results of the potential based modelling can then be compared with the actual production based modelling results to determine expected welfare grains.

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