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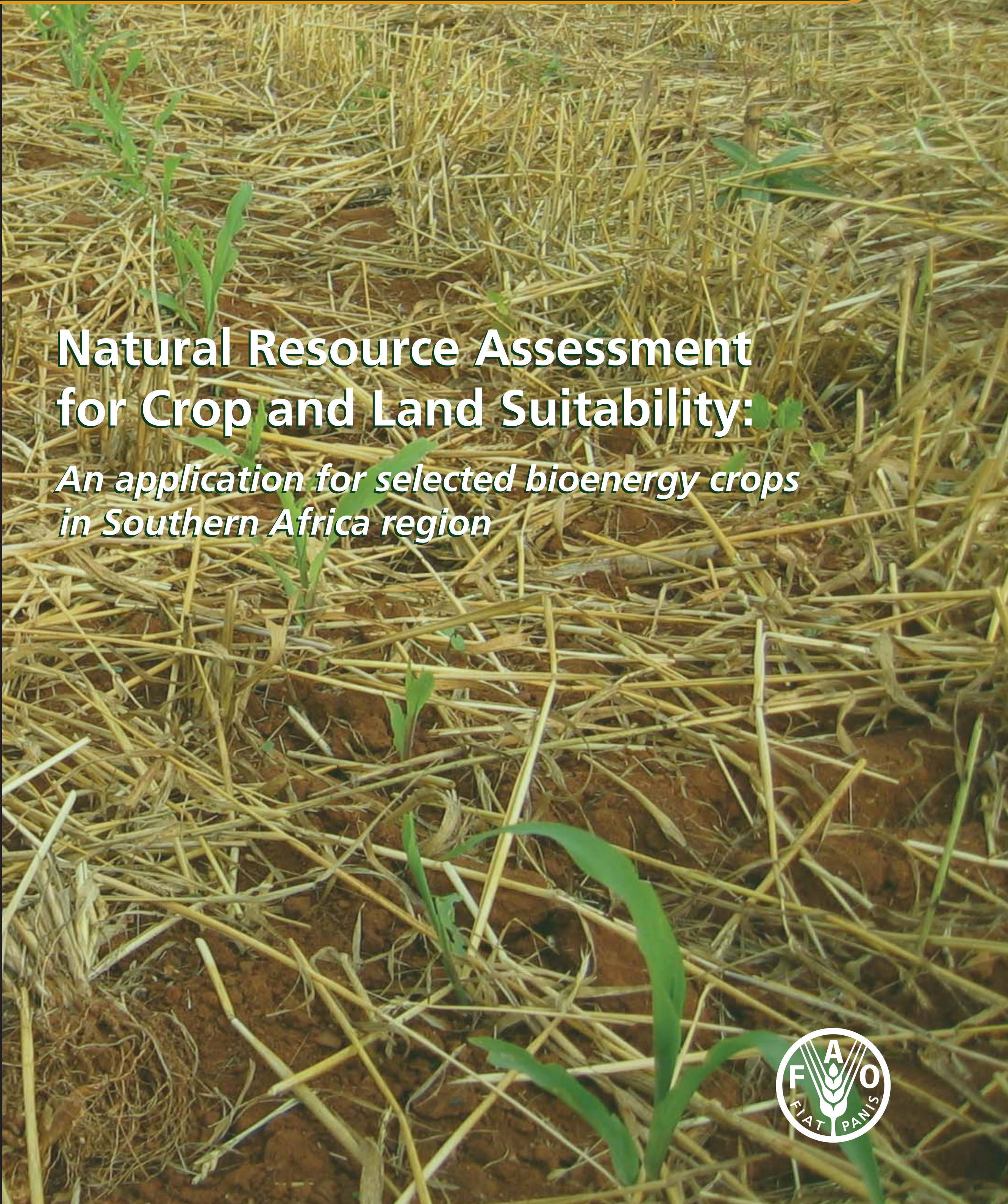

Natural Resource Assessment for Crop and Land Suitability:

An application for selected bioenergy crops in Southern Africa region

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An application for selected bioenergy crops in Southern Africa region

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FOREWORD

The cost of fossil fuel is soaring, and dependency on fossil fuels for energy is affecting the poor throughout the world with devastating effect. Increasing advocacy in favour of biofuel production worldwide and demands for new sources of energy have resulted in a growing interest in the domestication and cultivation of annual and perennial bioenergy crops, in particular species that are underutilized. Developing countries may be able to diversify their production and cope with increasing demands for energy by entering into bioenergy crop production.

However, there are constraints that must be considered before countries should make decisions to raise crops for biofuels, and many issues must be clearly articulated and managed beforehand. Among the issues to be addressed are the economic and environmental pressures on natural resources; the connected interrelationships among land resources for potential agricultural production; current and future land use to meet food security needs while managing an optimal balance of land use for crops, biofuels, habitat conservation, sustainable forestry, and so on; and the possible impact of biofuel land uses on food and energy security. To date, little systematic information on the agro-ecological conditions most favourable to cultivating many of these bioenergy crops has been available at national and regional level. Moreover, the way in which bioenergy crops can fit into a wide range of environmental and agricultural conditions is not well known.

Over the past 15 years, the ECOCROP database established by FAO has been used for global, regional and national assessments of agricultural potential. With ECOCROP, it should be possible to make use of the agro-ecological zones (AEZ) methodology and procedures, in conjunction with digitally referenced geographical databases, to characterise the crop and land suitability of plant species best adapted to different environments and uses. ECOCROP contains basic crop environmental information and makes possible the identification of plant species by matching important climate and soil requirements with the data on soil and climate entered by the user. There is thus every reason to believe that incorporating bioenergy crop requirement data into ECOCROP will help to map out suitable land areas where bioenergy crops can be developed in a cost-effective manner. It is important that suitable areas begin to be inventoried for national development strategies. Such information can assist policy-planners and decision-makers to formulate strategies and build capacity so as to support biofuel policy development, planning and implementation. However, it was recognized that no strategy would be successful if current application and mapping functions of ECOCROP were not first adequately enhanced and expanded. Hence, the FAO Inter-Departmental Working Group on Bioenergy (IDWG-Bioenergy) provided a platform for cross-sectoral collaboration and critical resources for developing database-mapping functions and for strengthening land assessment activities related to bioenergy.

The pilot regional assessment described in the present publication was designed to initiate support for suitability assessments of bioenergy crops that are also food crops, namely cassava, sugarcane, sweet sorghum, sunflower and oil palm under rainfed production in developing countries in Southern Africa region. The goal of this work is to strengthen national policy and development capacity by providing critical bioenergy crop adaptability and land resources information (including mapping) to policy and decision-makers for socio-economic development. The assessment provides an up-to-date GIS database on climate, soil, terrain and vegetation, as well as critical data sets, methodological and analytical support and integration of FAO's AEZ methodology including an inventory of land resources and specific ecological and agronomic adaptability requirements for selected bioenergy crops. The assessment also enhances and expands the current ECOCROP database and its applications by adding more detailed information on bioenergy crops and a mapping function to provide support to countries for decision-making and strategy development. This publication seeks to assist government and institutional policy- and decision-makers in identifying places where energy crops could be grown and in understanding the geographic (agro-ecological and economic) context of bioenergy supplies, at country and regional levels. We trust that it will not only increase awareness about the environmental challenges related to bioenergy crops production systems, but also contribute to the development of new production practices and technologies for sustainable intensification in the context of "Save and Grow"– a new FAO approach that will help cut agriculture's contribution to climate change.

While aimed primarily at decision-makers, this publication will also be a valuable source of information for programme managers, international and multilateral development organizations, donors, NGOs, and the private sector – as well as researchers, advisors, teachers and professionals in agriculture. We trust that it will help to further strengthen FAO in-house technical capability for additional assessments within the context of national capacity development for land-use planning for bioenergy crops that are also food crops.

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Development of the *Natural resource assessment for crop and land suitability: An application for selected bioenergy crops in Southern Africa region* was initiated at the end of 2009 within the context of the International Bioenergy Platform and its cross-sectorial collaboration, facilitated by FAO's Climate, Energy and Tenure Division (NRC) in partnership with FAO's Plant Production and Protection Division (AGP).

The preparation of the assessment described in this report has benefited FAO Bioenergy and Food Security (BEFS) project, which was funded by the Government of Germany and was one of the first efforts to ensure that food security concerns were taken into account within the bioenergy sector. Thanks to the BEFS project, opportunities for bioenergy development were explored, and tools for making informed decisions taking into account food security issues in the broader context of rural and agricultural development were made available. An analytical framework was developed in 2010 which included four key areas, of which one is related to natural resource analysis. Under the project, the crop and land suitability assessment software was developed for country analysis; for the purposes of this report the capability of the software and the analysis were extended so as to carry out the regional suitability assessment.

FAO Bioenergy Cross-sectoral Funds helped provide a campaign to raise awareness of the need for bioenergy crop information and support for its development, and AGP provided additional resources and served as a catalyst for the initiative aimed at overcoming technical and policy constraints to bioenergy crop production planning and development. The work reported in this publication was initiated and coordinated by NeBambi Lutaladio and Eric Kueneman of AGP in conjunction with Jeff Tschirley of NRC. They benefited from the close collaboration of colleagues in AGP – Amir Kassam and Theodor Friedrich, and in NRC – Mirella Salvatore and Mario Bloise.

Special thanks for their technical expertise in the compilation of the regional land resources database and in the application of the AEZ crop and land suitability methodology are due to Amir Kassam, Mirella Salvatore and Mario Bloise. Inputs from Michela Marinelli in the preparation of the climatic resources inventory and the contribution of participating experts and interested individuals in reviewing, providing constructive suggestions and in technical editing is gratefully acknowledged. Thanks are also due to Magda Morales for formatting the draft for printing and Claudia Tonini for the graphic layout.

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ACRONYMS AND ABBREVIATIONS

AEZ	Agro-ecological zone
BEFS	Bioenergy and Food Security
CA	Conservation Agriculture
CC	Climate change
CLSA	Crop and Land Suitability Assessment
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DUE	Data User Element
ECOCROP	The Crop Environmental Requirement database and the Crop Environmental Response database
EEA	European Environmental Agency
ESA	European Space Agency
FAO	Food and Agriculture Organization
GAUL	Global Administrative Unit Layer
GIS	Geographical Information System
GOFC-GOLD	Global Observations of Forest Cover and Global Observations of Land Dynamics
HWSD	Harmonised World Soil Database
IGBP	International Geosphere-Biosphere Programme
ISRIC	International Soil Reference and Information
ITCZ	Inter-Tropical Convergence Zone
IUCN	International Union for Conservation of Nature
JRC	European Commission's Joint Research Centre
LCCS	Land Cover Classification System
LGP	Length of growing period
LUT	Land Utilization Type
MERIS	Medium Resolution Imaging Spectrometer
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency
NIMA	National Imagery and Mapping Agency
PMUR	Poverty Mapping Urban and Rural
SCPI	Sustainable crop production intensification
SI	Suitability Index
SOTER	Soil and terrain digital database
SRTM	Shuttle Radar Topography Mission
TA	Tillage-based agriculture
UNEP	United Nations Environment Programme
UNFPA	United Nation Population Fund
VMAP0	Vector Map Level 0
WPDA	World Database on Protected Areas

EXECUTIVE SUMMARY

The growing demand for agricultural commodities to produce biofuels is a new force putting additional pressure on agricultural markets, in part through increased demand for agricultural commodities that have led to higher commodity prices. Concern exists over the potential impact of the demand for bioenergy crops on the food security of the poor. At the same time, the environmental effects of biofuels are under scrutiny, especially with respect to carbon sequestration and land use. Clearly, there is no "one-size-fits-all" bioenergy model; food security must always come as a first priority, and all countries should carefully consider their agricultural objectives and the means they use to encourage use of biofuels.

Natural resource assessment for crop and land suitability could help to ensure that bioenergy developments do not negatively influence short-term and longer-term food production and food security, or the environment (including protected areas, biodiversity, forests, etc.). To understand the complexity of the challenges involved and respond to them better, policy-planners and decision-makers need reliable technical information to help decide whether a country has enough land for bioenergy crops, or how existing land could produce more to allow for both food and bioenergy crop production. Investment decisions need to be based upon whether the two sectors can be managed in a balanced and sustainable way without putting the food security of the country at risk.

With these considerations in mind, FAO undertook the joint pilot work for this publication. The main objectives of the work were to:

- provide a regional assessment of crop and land suitability for selected bioenergy crops – cassava, sugarcane, sweet sorghum, oil palm and sunflower– in Southern Africa region, which would involve a comparison between tillage-based production systems and Conservation Agriculture systems; and
- strengthen in-house technical capability and awareness such that further bioenergy assessments and capacity development could be carried out during national planning exercises.

The methodology used is based on the FAO agro-ecological zones (AEZ) approach to crop and land suitability assessment. It is also in line with Sustainable crop production intensification (SCPI) principles, which strengthen the resilience of farming systems to socio-economic and climate risks. The reported work is a contribution to development planning processes and could be used to evaluate and test scenarios of bioenergy potential and food security risks for different time frames. Such information could be utilized by policy-makers and institutions in planning for a sustainable long-term use of national land and rural resources for development.

The immediate outputs of the assessment are: (i) the characterisation of the climatic and soil resources of the region as part of the land resources inventory; and (ii) the analysis of crop agro-climatic suitability and crop land suitability under two production systems, each at two levels of production and management inputs.

The results of the assessment in Southern Africa region can be summarized as follow:

- Sweet sorghum for bioethanol production and sunflower for biodiesel production show relatively high potential.
- Cassava for bioethanol production has good potential, but it should be taken into account that this is a staple food crop, second only to maize in most of the countries in the region.
- Sugarcane for bioethanol production and oil palm for biodiesel production have very limited potential under rainfed conditions for both production systems and at all levels of inputs.
- A high level of production and management inputs considerably increases potential production capacity, but in countries where accessibility to agricultural inputs is one of the most limiting factors, cost analysis and affordability studies would need to be carried out.
- The production management system greatly influences the extent of both potential suitable land and production, as can be seen by better agro-climatic and agro-edaphic suitability under a Conservation Agriculture system.

The land resources base and the crop and land suitability methodology are now fully available to assess additional crops to establish the geographical distribution of agro-ecological potentials. The portfolio of crops and production systems can then be deployed for other planning applications such as: linking productivity to ecosystem services sustainably; ecosystem services and climate change; land allocation for food security; research and extension; and capacity development.

CHAPTER 1
Introduction

1.1 CHALLENGES AND SCENARIOS

From 16–18 November 2009 world leaders participated in the World Summit on Food Security held at the Headquarters of the Food and Agriculture Organization of the United Nations (FAO) in Rome and renewed their commitment to eradicate world hunger. Three important events had prepared the way for this Summit:

- How to Feed the World in 2050, 12–13 October 2009
- Committee on World Food Security, 14-15-17 October 2009
- The original World Food Summit, 13–17 November 1996

Each of these events highlighted the new challenges that the agriculture sector is facing: rapidly growing populations, increasing incomes that induce changes in consumer preferences (such as increased meat consumption), additional demands for both environmental services and production, and finally, stagnating investment in agriculture at both the national and international levels.

On the one hand, agriculture, especially for small- and medium-holders, has traditionally produced a wide variety of products – from food to livestock to fibres and other goods. In addition to the traditional demand for food, there is a highly significant new demand, namely growing crops – including food crops – as a source of bioenergy and raw material for other industrial purposes.

There is also a growing trend to ensure that agriculture produces crops on a sustainable basis. Numerous agro-ecosystem services, such as soil formation, nutrient cycling, food, fresh water, fuelwood, fibre, biochemicals, genetic resources, climate regulation, disease regulation, water purification, pollination; and many cultural services, such as spiritual practices, aesthetics, and heritage, were often considered “free” resources in the past. Today they are being recognized for their contribution to human well-being and economic growth.

Can the agriculture sector respond successfully to the additional new demand to produce crops for biofuels?

To date, the boom in liquid biofuels has been driven largely by policies in developed countries seeking to mitigate climate change by increasing their energy security and supporting their agricultural sectors. In the *State of Food and Agriculture* 2008, FAO explored biofuels by analysing their prospects, risks and opportunities, and the implications of their recent rapid growth.

The growing demand for agricultural commodities to produce biofuels is an additional driver that has affected agricultural markets, in part through increased demand for agricultural commodities that have led to higher commodity prices. Concern exists over the potential impact of the demand for bioenergy crops on the food security of the poor. At the same time, the environmental effects of biofuels are under scrutiny, especially with respect to carbon sequestration and land use. Clearly, there is no "one-size-fits-all" bioenergy model; food security must always come as a first priority, and all countries should carefully consider their agricultural objectives and the means they use to encourage use of biofuels.

Nevertheless, at the same time biofuels can provide an additional avenue for agricultural diversification, income generation and rural development. They could help alleviate the chronic energy shortfall that exists in many of the poorest rural communities. Careful analysis of the agriculture value chain and its capacity to produce a range of products will reveal that there is often space to consider diversification towards biofuels. But reaping these benefits will be possible only if the appropriate policies, investments and management systems have been established beforehand. There is little doubt that over-reliance on maize and seed oils to produce biofuels is not a sustainable solution.

The effects of climate change introduce additional uncertainty about the capacity of agriculture to meet the diverse demands being placed upon it. High and volatile prices for food and agricultural commodities are a reflection of this uncertainty. They have strongly affected global markets since 2008 and are expected to do so for the longer term.

More than ever, decision-makers need clear evidence to demonstrate that the food production and food security priorities they are deciding have ensured a balanced use of the land in the context of all demands at national, regional and global levels, and that agriculture is making the most of its contribution to a country's well-being.

To understand the complexity of the above challenges and respond to them, decision-makers require policy-relevant information about land resource potential for agriculture, in addition to current and future land use demands to meet food security needs. They also need to consider land use in the broader context of demands for biofuels, habitat conservation and forestry and the possible impact of such land uses on food security.

The methodology reported in this publication is a contribution to such proactive development planning processes. It can be used to evaluate challenges and test possible scenarios so that estimates of potential areas at risk for different future time horizons may be produced. Such information could be taken into consideration by policy-makers and institutions in planning for a sustainable long-term use of national land and rural resources for development.

1.2 MAIN OBJECTIVE AND SCOPE OF THE REPORT

The main objective of the work reported in this publication is twofold:

- provide a regional assessment of crop and land suitability for selected bioenergy crops – cassava, sugarcane, sweet sorghum, oil palm and sunflower– in Southern Africa region, involving a comparison between tillage-based production systems and Conservation Agriculture systems; and
- strengthen in-house technical capability and awareness such that further bioenergy assessments and capacity development could be carried out during national planning exercises.

The assessment finds its relevance in the light of the recent increased interest in bioenergy development which could negatively affect food production if not managed on an informed basis. Natural resource assessments for crop suitability could help to ensure that bioenergy developments do not influence either short-term and longer-term food production, or impact negatively on food security or the environment (through destruction of protected areas, reduction of biodiversity, deforestation, and so on). Policy-makers need the information from such assessments to help decide whether a country has enough land for bioenergy crops and, if not, how existing land can yield more produce to allow for both food and bioenergy crop production, and how can the two sectors be managed in a sustainable way.

Chapter 2 describes the overall framework and the potential applications for development planning. Chapter 3 describes the preparatory steps in the land resources inventory required to perform the crop and land suitability analysis. Chapter 4 illustrates the methodological framework for assessing the crop and land suitability and all the steps required to perform the analysis. Chapter 5 identifies the availability of land and the socio-economic context to take into account in the analysis. Finally, Chapter 6 shows the results of the application for biofuel feedstocks. A CD in the back pocket provides an easy tool containing the land resources information compiled for the study region and the full results of the assessment.

CHAPTER 2

The framework for land resources appraisal and development planning

Today's national agricultural development challenges include food insecurity, widespread poverty, increasing energy and input costs, continuing degradation of agricultural land and decrease in biodiversity, water scarcity, climate change, globalisation and lack of international cooperation and partnerships. To respond to these challenges, countries and regional groups of countries must be able to develop and use databases of national land and agricultural resources to identify the best possible alternatives for investment in agriculture and rural development.

Reliable information has always been fundamental for the policy planning and institutional support needed for agricultural development. Over the past century the constant challenge for agriculture was to produce higher yields from a given set of inputs. The Green Revolution in Asia during the 1960s was one of the best examples of how the productivity challenge was met with great success, largely through cultivation of high-yielding varieties. The continuing challenge to increase the efficiency of the agricultural production system remains with us to this day, and with ever greater urgency and complexity.

Over the years, FAO has provided various methods to strengthen national capacity for development planning. The agro-ecological zones (AEZ) approach, which has been applied at regional and national levels for many years, has been widely recognized and used for numerous applications. In response to emerging challenges and development issues, the AEZ approach has been adapted to incorporate new knowledge, technology and analytical approaches (Annex 1).

Bioenergy crops are currently attracting considerable attention because of their potential economic and environmental advantages as well as the possible role they could play in poverty alleviation. However, these crops compete with food crops for good agricultural land, and in situations of land scarcity they can weaken national food security if suitable land for food crops or the capacity of the country to import food at competitive prices is not adequately taken into account.

The key here is to understand the agro-ecological potential of the land, while taking into account the role that crop and soil biology play in sustainable agriculture, and particularly in programmes to intensify such agriculture. Conservation agriculture (CA) systems are more sustainable, and economically, environmentally and socially superior to conventional tillage-based production systems. CA systems are also “climate-smart” in terms of adaptability and mitigation, requiring less energy and fewer agro-chemicals, thus producing more for less.

With this in mind, FAO’s Natural Resources and Agriculture and Consumer Departments undertook joint pilot work on five specific bioenergy crops to assess crop and land suitability at the regional level in one selected area, namely Southern Africa, and involving a comparison between tillage-based production systems and CA systems.

The methodology that was used called for coordinating and correlating multi-layered land resources inventory and layers of information on other land uses, with crop and land suitability assessment information. The resulting land resources base and the crop and land suitability methodology, having thus been tested in the assessment we describe in this report, can now be used to assess additional crops to establish the geographical distribution of agro-ecological potentials. The portfolio of crops and production systems can then be deployed for other planning applications as described in the following sections.

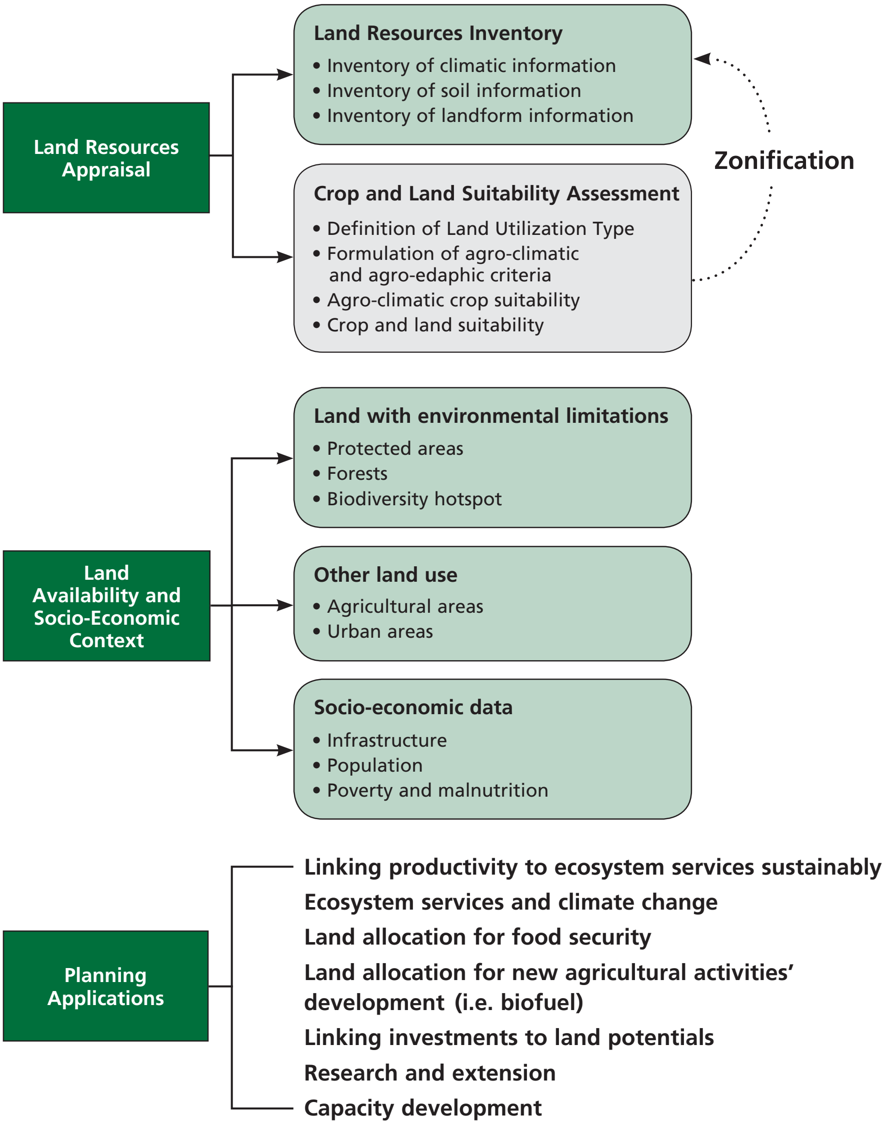
The Land Resources and Planning Framework is schematically described in Figure 2.1.

2.1 LINKING PRODUCTIVITY TO ECOSYSTEM SERVICES SUSTAINABLY

Agriculture everywhere is being transformed towards systems that permit intensification without compromising on ecological sustainability. This implies producing more from the same area of land while increasing agriculture’s contribution to the natural capital and the flow of environmental services. Such systems are based on an agro-ecological approach exemplified by three core principles of CA: reduced or minimal soil disturbance practices; permanent soil cover; and crop rotations or associations, applied simultaneously together with other good agricultural practices related to integrated crop, nutrient, water and pest management.

These systems offer a range of advantages such as *climate adaptability* through better soil moisture regimes, or *climate change mitigation* through reduced greenhouse gas emissions and increased soil carbon sequestration. Such agro-ecological systems also avoid land degradation and enhance the land resources base through improvements in soil health and soil organic matter. These practices increase soil biota microorganisms and meso-fauna, water infiltration and drainage, soil moisture holding capacity, cation exchange capacity and soil aeration. They reduce soil compaction and eliminate hard plough pans, runoff and soil erosion, thus reducing pollution in water systems from soil particles, soil microorganisms and agro-chemicals. The improvements in the hydrological cycle with CA systems mean that water

FIGURE 2.1
Land Resources and Planning Framework



resources and watershed services can be augmented in terms of quantity as well as quality with respect to sustainable intensification goals.

These positive effects and their resulting higher productivity (efficiency) along with their economic, environmental and social implications increasingly need to be taken into account in development planning. By using the national and regional land resources database and crop suitability assessment approach described in this publication, it is possible to simulate the impact of sustainable intensification on various environmental parameters.

2.2 ECOSYSTEM SERVICES AND CLIMATE CHANGE

Societies everywhere benefit from the many resources and processes supplied by nature. Collectively these are known as ecosystem services, and include the provisioning services of clean drinking water, and edible and non-edible biological products; processes that decompose and transform organic matter, carbon sequestration, and biologically fixed nitrogen; regulatory services that control air quality, soil erosion, pest and diseases, natural hazards; and supporting services of soil formation, nutrient cycling, water cycling, pollination (MEA, 2005). These ecosystem services operate at various nested levels from field scale to agro-ecological or watershed scale and beyond.

CA facilitates ecosystem services on agricultural land, particularly those services related to provisioning, regulating and supporting, and those derived as a result of improved conditions in the soil volume used by plant roots (Kassam *et al.*, 2009). The improvement in the porosity of the soil is effected by the actions of the soil biota, which are present in greater abundance in the soil under CA. The mulch on the soil surface in CA systems protects against the compacting and erosive effects of heavy rain, buffers temperature fluctuations, and provides energy and nutrients to the organisms below the soil surface.

When these effects are reproduced across farms in a contiguous micro-catchment area within a landscape, the ecosystem services provided – such as clean water, sequestration of carbon, avoidance of erosion and runoff or of dust clouds – become more apparent. The benefits of more water infiltrating into the ground beyond the depth of plant roots is perceptible in terms of more regular stream flow from groundwater through the year, and/or more reliable yields of water from wells and boreholes. The benefits of carbon capture become apparent in terms of the darkening colour and more crumbly ‘feel’ of the soil, accompanied by improvements in crop growth, plus less erosion and hence less deposition of sediment in adjacent waterways. Legumes in CA rotations provide increased in situ availability of nitrogen, thus diminishing the need for large amounts of applied nitrogenous fertilizers.

The entire society benefits from CA, regardless of farm size, through diminished erosion and runoff, less downstream sedimentation and flood damage to infrastructure, better recharge of groundwater, and more regular stream flow throughout the year, resulting in a more reliable community water supply and overall better quality water. Cleaner civic water supplies also reduce treatment costs for urban/domestic use. CA contributes to increased stability of food supplies as well, because crops are more resilient when confronted with drought. The rural community ultimately benefits from better nutrition, overall health and less pressure on curative health services.

In CA systems, the sequences and rotations of crops also encourage agrobiodiversity, because each crop attracts different overlapping spectra of microorganisms. The optimization of populations, range of species and effects of the soil-inhabiting biota are encouraged by recycling crop residues and other organic matter that provide the substrate for their metabolism. Crop rotation inhibits the infestation of weeds, insect pests and pathogens by interrupting their life cycles, making them more vulnerable to natural predator species, and by contributing to development-inhibiting allelochemicals. The same crop mixtures, sequences and rotations provide aboveground mixed habitats for insects, mammals and birds.

Under CA systems, it is possible to harness so many of the above-mentioned ecosystem services mostly because the ecosystem functions which generate these services are being enhanced and protected; agriculture is no longer in competition against nature but working in harmony with it.

The methodology described in this publication could be further developed in order to quantify potential effects of crops and crop production methods on specific ecosystem services such as carbon sequestration, or biological nitrogen fixation, or control of runoff and erosion. CA is considered to be a “Climate Smart Agriculture” system because it allows producers to harness higher productivities (“more for less”), while at the same time it offers greater climate change adaptability and climate change mitigation, thus imparting a greater degree of resilience and sustainability to agricultural production. The land suitability methodology can help assess the implication of climate change on food security based on different production systems such as tillage-based agriculture and CA. It can also help to assess the mitigation potential of other CA based systems, such as the System of Rice Intensification (SRI), organic farming, agroforestry or crop-livestock systems.

2.3 LAND ALLOCATION FOR FOOD SECURITY

The immediate outputs of this pilot regional study are the production estimates for bioenergy crops that are also food crops. With further work, additional crops can be added to the crop portfolio to provide such estimates. By comparing such estimates with existing production of these same crops, attention can be drawn to the priority land areas for future expansion and development of food security, and thus also provide a basis for crop forecasting and early warning programmes that are at the heart of food security management.

By using optimisation programmes that can operate on estimates of crop and land potentials, the most advantageous crops and best management levels for specific areas can be identified and selected according to policy objectives.

These can be used to maximize food production in terms of calories, meet particular employment levels, optimise profit on either an area or a cash-crop basis, or provide for other perceived needs. From the estimates of calorie and protein production, it is possible to estimate potential population (human and animal) support capacity on the basis of agro-ecological units or administrative units, and thus orient population planning, agricultural development and related research. Food security measures can then be planned according to the indicated priorities.

Feeding future national, regional and global populations will require the allocation of the best land to agriculture: but the reality is that good agricultural land is often found near urban areas and is used for further urban expansion. The ability to identify the conflicts as well as the solutions to resolve them is essential. This study demonstrates that it is possible to identify land which is essential for future food security and which can also be considered suitable for bioenergy purposes. A separate study exercise will be necessary in order to determine the precise allocation and the mixture of crops.

2.4 LINKING INVESTMENTS TO LAND POTENTIALS

If estimates of crop and land potentials based on production systems and levels of inputs can be made, then key decisions on shorter- and longer-term investments for agricultural and rural development can be aligned with the estimates in order to meet production, economic, environmental and social objectives. Estimates can be carried out at the national as well as regional level, allowing strategic alliances to be forged between countries and groups of countries based on the potential of the land resources of each.

Such investments can include roads and transport networks, local and national food storage networks, investments for “low-carbon footprint” agriculture involving equipment and machinery for CA production systems (including crop-livestock systems), irrigation development, veterinary services, agriculture insurance and finance, agricultural education, research and extension, public-private partnerships, farmer organisations, investments in input supply chains, output value chains and markets, payments for environmental services, etc.

2.5 RESEARCH AND EXTENSION

The agricultural paradigm is changing, and it requires a better definition of the natural resource base and crop and land potential, so that constraints and opportunities can be identified and geographically referenced. For example, in the case of CA, empirical evidence shows that while CA principles are universally applicable, the solutions must be adapted locally to suit prevailing socio-economic conditions, and local biophysical and other constraints, such as lack of sufficient biomass to meet all functional needs, or lack of appropriate equipment and machinery, must be taken into consideration.

The land resources inventory created in this report indicates the nature and distribution of agricultural land resources in Southern Africa region. Many of the steps in the crop and land suitability assessments need to be placed within a local context and adapted to those conditions. Information derived from research and extension in each country can be integrated in new assessments carried out by national teams as part of development planning for research and for extension.

Agro-ecological production systems tend to be management-intensive and require a participatory approach to learning in order to be effective; this means that farmers learn by doing. Extension agents therefore need to be able to set up benchmark "proof of concept" demonstration sites, both on-farm and on-station, to ensure that the locally derived solutions can be discovered and disseminated through participatory mechanisms. To establish relevant innovation systems involving farmers and all other stakeholders, information generated by the study can inform extension institutions and farmers' organisations concerning the potentials of different crops and practices. This can strengthen extension and research planning at the same time that shorter- and longer-term research is being undertaken. A land-resources inventory of the region can provide an efficient way of deciding on the research and extension effort to reach maximum numbers of farmers.

2.6 CAPACITY DEVELOPMENT

The methodology presented in this publication is of a multidisciplinary nature, and for national development planning in any country, there needs to be an explicit effort made to establish local capability and capacity to engage in such crop and land suitability assessments. Crop suitability assessments can only be an entry point into developing capacity, which eventually must cover not only crops but also livestock, pastures, trees, perennial crops and various farming systems, among others. In a given country, a programme involving all the relevant institutions must be set up to undertake the creation and maintenance of the country's land resources inventory at an appropriate scale so that reliable results can be obtained upon which to base technical and policy decisions.

The inventory created for this study is relatively simple; it can be made more sophisticated by analysing historical daily records of climatic parameters, as well as locally derived information on crop performance in different agro-ecological zones. Information on climate adaptability and the mitigation potential of conservation agriculture practices in different agro-ecological zones, on greenhouse gas emissions, and on carbon sequestration potentials would also be relevant. Information on input-output functions, as well as on insect pests, pathogens and diseases, and weeds could also greatly enhance the initial findings of this study. These are exercises that adapt well to being carried out by national and local stakeholders.

The experience gained in this pilot regional study can be used to promote national-level capacity development and to establish and sustain planning and programme implementation based on crop and land potential assessments that take into account new agro-ecological production systems such as conservation agriculture. Such an approach will contribute largely to more sustainable agriculture intensification in developing regions and to better-informed decision-making in managing the balance between food security and bioenergy crops.

CHAPTER 3

Land resources inventory

The productive ability of land is limited. Production limits are set by biophysical factors, namely climate, soil and landform conditions, combined with human-induced factors such as land use and management. Knowledge of the biophysical factors and their potential is thus essential for planning optimal land use and subsequent sustainable long-term agricultural and economic development. In this report the inventory of biophysical factors was carried out in 11 African countries, namely Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe. For simplicity, the term "study region" will be used for referring to this specific Southern Africa region.

The biophysical factors inventory consists mainly of two resources inventories, namely climatic resources and land resources. Furthermore, information on land use, law-constrained land (i.e. protected areas, concessions) and socio-economic indicators were collected to link the analyses to country reality. In the following sections, the main inventories as well as additional information are described in order to help the reader to become familiar with the study region. The sources of the maps are presented in Annex 2.

3.1 CLIMATIC RESOURCES INVENTORY

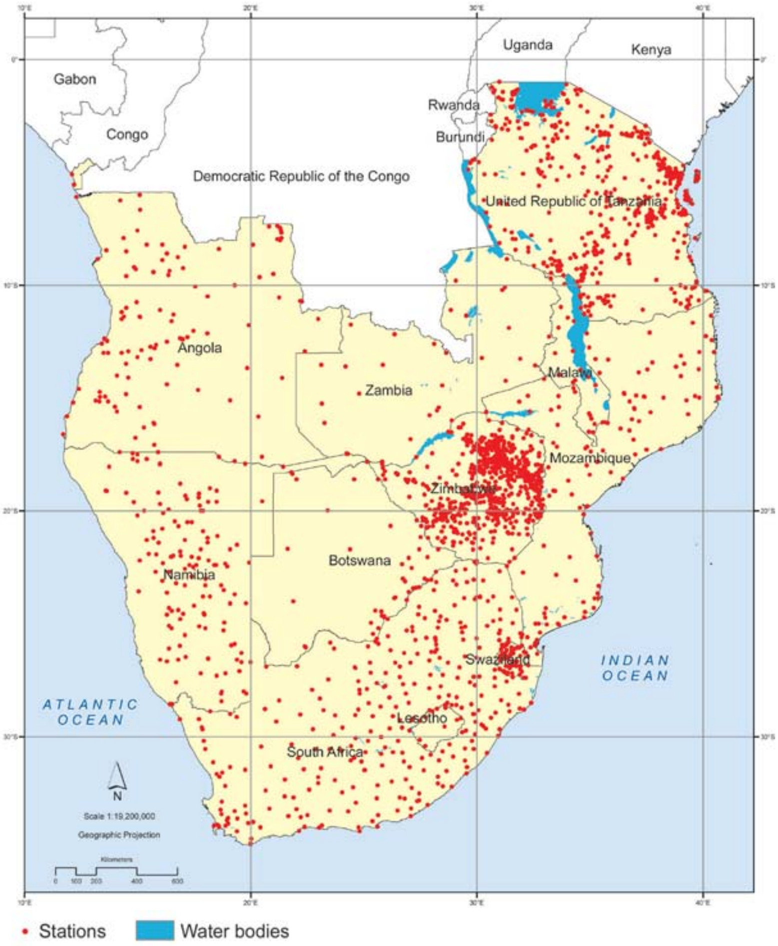
The climatic resources inventory was generated from information gathered at nearly 2000 meteorological stations across countries extracted from the FAO New_LocClim database.

As can be seen in Figure 3.1, the stations are not equally distributed within the study region. Botswana, Namibia and Angola, in particular, have only a very limited number of stations, which affects the accuracy of the interpolated surface with respect to the extent of their territory.

The main climatic data required to perform the land suitability assessment are temperature, radiation, precipitation and evapotranspiration. Temperature and moisture availability are key factors in determining the distribution of rainfed crops. In combination with solar radiation, these climatic factors condition photosynthesis and allow plants to accumulate biomass according to their eco-physiological rates and patterns. Depending on the location, further information is required to characterize in detail the climate zones, rainfall and growing period patterns.

Long-term monthly average data on temperature, radiation, precipitation and evapotranspiration (dating back to 1971) from these meteorological

FIGURE 3.1
Meteorological stations



stations were used in combination with altitude and rainfall patterns to generate the three primary climate datasets: climate zones, thermal zones and length of growing period (LPG) zones.

3.1.1 Major climate zones

Major climates are defined by the prevailing climatic conditions based on the average monthly temperature, and whether rain falls mainly in the summer or winter season (FAO, 1978–81). The major climate zones in Southern Africa region represent the major latitudinal belts, namely the tropics and subtropics with summer or winter rainfall.

The zones were identified following the classification reported in Table 3.1.

TABLE 3.1

Major climate classification

Climate zones	Description
Tropics	All months with monthly mean temperatures, corrected to sea level, above 18°C
Subtropics	One or more months with monthly mean temperatures, corrected to sea level, below 18°C but above 5°C
Subtropics summer rainfall	• Northern hemisphere: rainfall in April–September ≥ rainfall in October–March • Southern hemisphere: rainfall in October–March ≥ rainfall in April–September
Subtropics winter rainfall	• Northern hemisphere: rainfall in October–March ≥ rainfall in April–September • Southern hemisphere: rainfall in April–September ≥ rainfall in October–March

In the study region the three climate zones are geographically distributed as shown in Figure 3.2. The tropics cover almost 80 percent of the area. The subtropics with summer rainfall (17.8 percent) can be found in the south and west of Namibia, in the south in Botswana, in all of Lesotho and in a large part of South Africa; the subtropics with winter rainfall (2.8 percent) is limited mainly to the west coast of South Africa. The extent of each climate zone by country is reported in Table 3.2.

TABLE 3.2

Extent of major climate zones by country as percentage of total land area

Country	Tropics	Subtropics (summer rainfall)	Subtropics (winter rainfall)	Total Land
	%	%	%	'000 ha
Angola	98.7	1.3	-	124,945
Botswana	85.9	14.1	-	57,178
Lesotho	-	100.0	-	2,968
Malawi	100.0	-	-	9,483
Mozambique	100.0	-	-	77,636
Namibia	73.3	23.9	2.8	82,083
South Africa	13.1	73.2	13.7	120,067
Swaziland	93.2	6.8	-	1,637
Tanzania	100.0	-	-	88,107
Zambia	100.0	-	-	73,638
Zimbabwe	100.0	-	-	38,318
Total	**79.4**	**17.8**	**2.8**	**676,060**

FIGURE 3.2
Major climate zones

3.1.2 Thermal zones

The thermal zones are defined by the amount of heat available for plant growth and development during the growing period, which is the time during which climate conditions, in particular rainfall, will permit adequate water supply for crop production. Temperature influences crop photosynthesis and growth rates as well as the developmental sequence of crop growth in relation to crop phenology. In some cases, temperature may determine whether a particular development process will begin and continue, or not. Less than optimal low temperatures can also delay flowering and fruit setting, or can lead to poor fruit setting and loss in yield and quality. In the same way, less than optimal high temperatures can cause heat and water stress and lead to poor quality and quantity of yield.

Figure 3.3 shows the map of reference temperature zones based on the following temperature groups (in degrees Celsius): >25.0, 25.0–22.5, 22.5–20.0, 20.0–17.5, 17.5–15.0, 15.0–12.5, <12.5 °C. The extent of each thermal zone as percent of total country land area for each country is presented in Table 3.3. Temperatures above 25 °C in the growing period are found largely in Mozambique, in Tanzania's coastal area and in a very limited coastal area in northwestern Angola. The lowest temperatures (below 15 °C) are in the southwest on the coast of Namibia and South Africa, and in Lesotho. At regional level, the predominant temperatures are in the range 20–22.5 °C, followed by 22.5–25 °C.

FIGURE 3.3

Reference thermal zones: mean temperature during the rainfed growing period

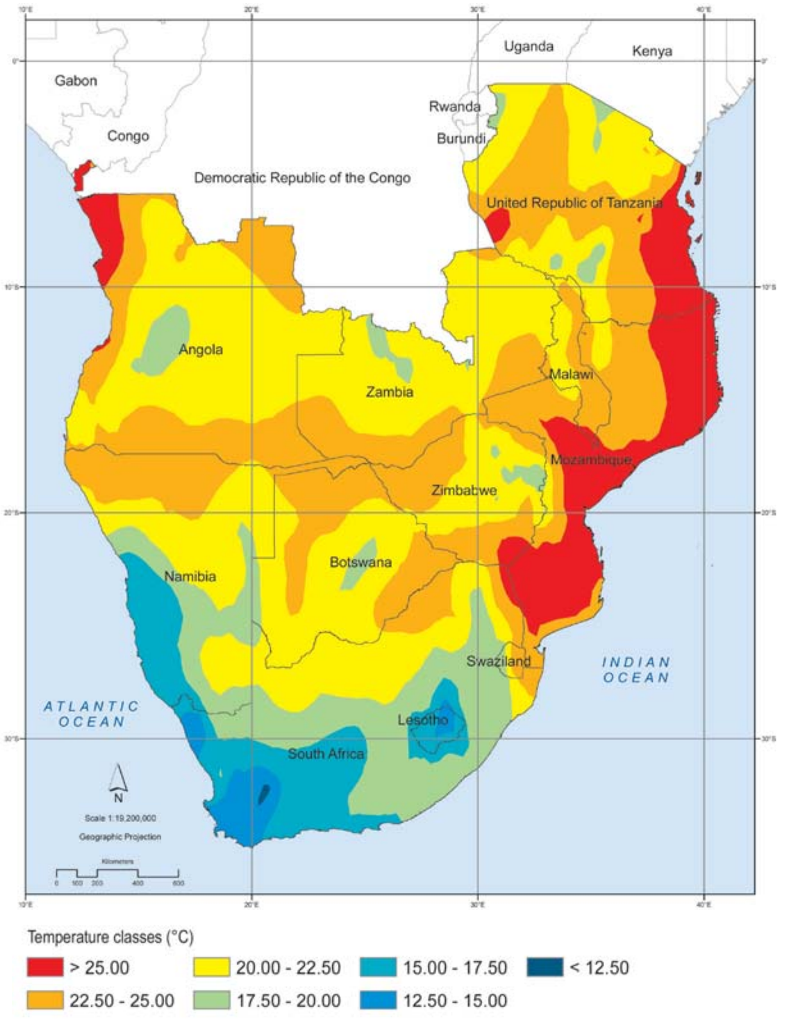


TABLE 3.3

Extent of thermal zones by country as percentage of total land area

Country	> 25	25 -22.5	22.5 - 20	20 – 17.5	17.5 - 15	15 - 12.5	< 12.5	Total Land
	%	%	%	%	%	%		'000 ha
Angola	5.1	33.5	56.7	4.7	-	-		124,945
Botswana	-	38.3	56.1	5.6	-	-		57,178
Lesotho	-	-	-	-	69.9	30.1		2,968
Malawi	4.0	52.4	43.6	-	-	-		9,483
Mozambique	57.1	38.0	4.8	0.1	-	-		77,636
Namibia	-	23.7	39.0	21.0	16.3	-		82,083
South Africa	0.7	7.2	23.5	37.8	23.1	7.5	0.2	120,067
Swaziland	-	51.3	25.6	23.1	-	-		1,637
Tanzania	16.3	41.2	38.2	4.3	-	-		88,107
Zambia	-	25.6	71.0	3.4	-	-		73,638
Zimbabwe	3.8	46.8	44.7	4.7	-	-		38,318
Total	**10.0**	**29.7**	**40.6**	**11.8**	**6.4**	**1.5**	**0.2**	**676,060**

3.1.3 Length of rainfed growing period zones and pattern

Average monthly rainfall (1971–2000) is the main information used to calculate the moisture availability used for crop development and growth. The moisture attributes are quantified using the growing period as the time reference; this is defined as the duration (in days) of the period during which the supply of available water in soil moisture, and from storage in the soil profile (set at a reference 100 mm), is greater than half of the potential evapotranspiration (ET). The calculation is based on a water balance model, comparing rainfall with ET. The length of the growing period (and the number of growing periods

TABLE 3.4

Extent of LGP classes by country as percentage of total land area

Country	0	1 – 29	30 - 59	60 - 89	90 -- 119	120 - 149	150 - 179	180 - 209	210 - 239	240 - 269	> 270*	Total Land
	%	%	%	%	%	%	%	%	%	%	%	'000 ha
Angola	-	1.1	1.1	2.4	6.3	15.3	17.4	23.7	24.5	8.2	-	124,945
Botswana	0.6	14.0	36.0	38.0	11.4	-	-	-	-	-	-	57,178
Lesotho	-	-	-	-	-	4.2	11.7	34.6	35.7	11.4	2.4	2,968
Malawi	-	-	-	-	-	16.0	58.1	20.9	4.4	0.6	-	9,483
Mozambique	-	-	0.8	3.1	3.5	23.0	48.2	12.1	7.3	2	-	77,636
Namibia	31.6	18.7	13.4	19.5	16.6	0.2	-	-	-	-	-	82,083
South Africa	13.6	20.8	13.1	10.0	9.9	8.3	6.7	9.7	3.6	1.7	2.6	120,067
Swaziland	-	-	-	-	3.0	10.0	33.8	24.7	27.3	1.2	-	1,637
Tanzania	-	-	-	-	0.6	20.3	42.2	32.0	4.4	0.4	0.1	88,107
Zambia	-	-	-	-	2.7	41.3	43.0	13.0	-	-	-	73,638
Zimbabwe	0.5	2.1	2.3	4.1	26.7	53.4	10.0	0.7	0.2	-	-	38,318
Total	**6.3**	**7.5**	**7.4**	**8.4**	**8.2**	**17.5**	**21.5**	**13.6**	**6.9**	**2.2**	**0.5**	**676,060**

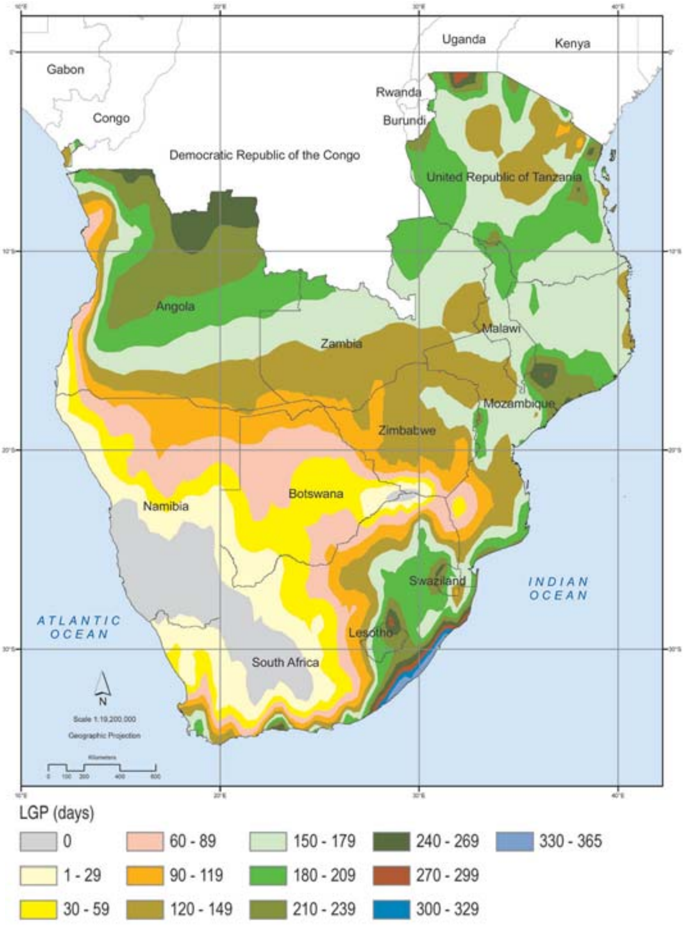
* the last three classes were aggregated because of the small area covered.

and dry periods per year) from a climatic point of view, and independent of crop, soil and landform, is therefore quantified in a referenced manner (Kowal & Kassam, 1978; FAO, 1979).

As shown in Figure 3.4 and described in Table 3.4 in terms of proportion of total land area, the arid zone (LGP < 60 days) covers a large part of Namibia, South Africa and Botswana; the dry semi-arid zone (60 < LGP < 119 days) is dominant in the coastal area of Angola and in the northern parts of Namibia and Botswana; the moist semi-arid zone (120 < LGP < 179 days) covers the southern part of Angola, almost all Zambia, Zimbabwe, Mozambique, and the central plateau of Tanzania; the sub-humid zone (180 < LGP < 269 days) is prevalent in the eastern part of South Africa, in the northern part of Angola, in the Zambezi river valley in Mozambique and in the remaining part in Tanzania; and the humid zone (LGP > 270 days) is limited to the east coast of South Africa.

FIGURE 3.4

Length of rainfed growing period zones



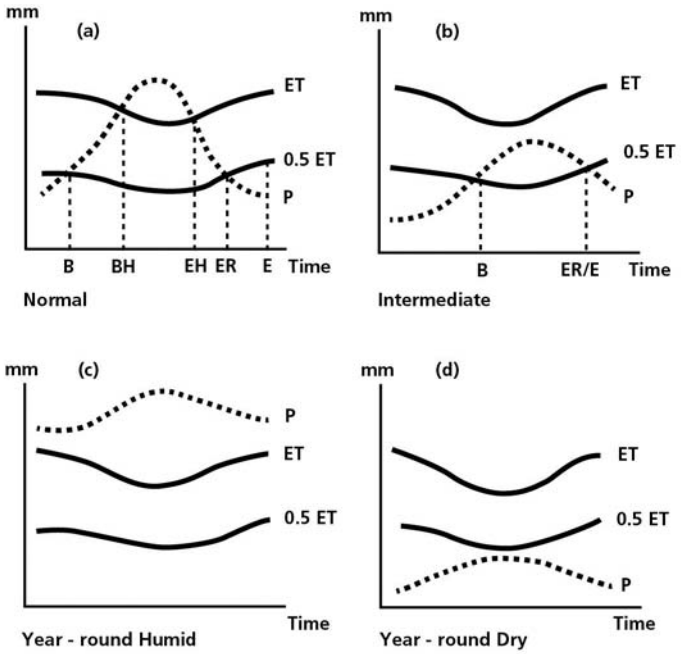
Several types of growing periods have been identified; these are schematically shown in Figure 3.5: normal, intermediate, year-round humid and year-round dry.

A normal growing period is made up of three moisture periods: the first intermediate moisture period followed by the humid period and concluded by the second intermediate moisture period.

The distinction between "normal" (a) and "intermediate" (b) is significant. Intermediate means that it is unlikely that full water requirements can be met during the rainy season without moisture conservation or a supply from groundwater or irrigation. In fact the growing period is defined as intermediate when the average precipitation does not exceed the full rate of the average ET, but it does exceed half the ET. The beginning and the end of such an intermediate growing period are defined as the points at which the precipitation curve crosses the 0.5 ET curve and there is no humid period. Year-round growing periods are: (c) year-round humid with rainfall exceeding full ET throughout the year, and (d) year-round dry with rainfall not exceeding half the ET throughout the year.

FIGURE 3.5

Types of growing periods

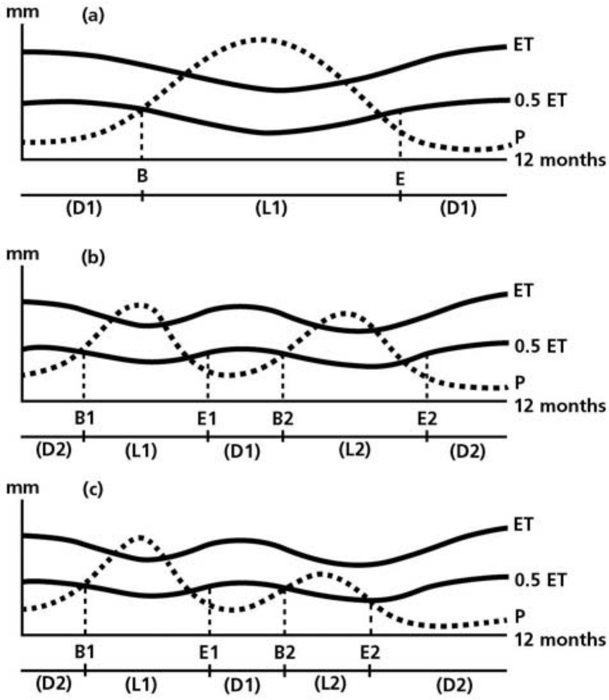


B – Beginning of growing period; BH – Beginning of humid period;
EH – End of humid period; ER – End of rainy season; E – End of growing period;
P – Precipitation; ET – Potential evapotranspiration

Furthermore, normal and intermediate growing periods could occur one or more times during the year, identifying the so-called LGP pattern. A theoretical representation is shown in Figure 3.6. The unimodal pattern is represented in (a): in a 12-months period only one normal growing period occurs. The bimodal LGP pattern arises when distinct growing periods occur and they are separated by a dry period, where the precipitation is less than half the ET. In Figure 3.6 a bimodal "normal" pattern is shown in (b), whereas in (c) a pattern composed by one normal growing period and one intermediate period can be found.

In the case of an LGP (b)-type pattern for the region, both growing periods are normal, and the second growing period is sufficiently long to ensure sufficient crop growth for a crop and land suitability assessment. In the case of an LGP (c)-type pattern, the second growing period is intermediate in nature and will not be long or reliable enough for crop production. Hence the

FIGURE 3.6
Numbers of growing periods

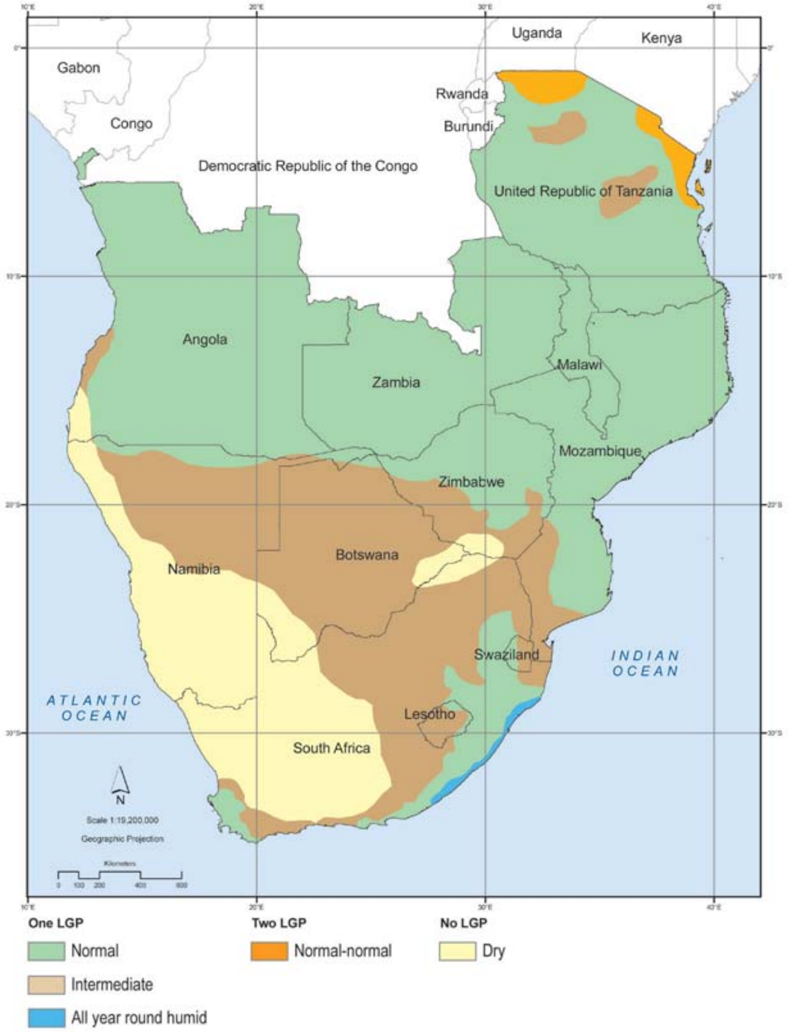


L1 – First growing period; L2 – Second growing period;
D1 – First dry period; D2 – Second dry period;
B1 – Beginning of the first growing period; B2 – Beginning of the second growing period;
E1 – End of the first growing period; E2 – End of the second growing period.

second growing period will affect crop and land suitability at the regional level in only a minor way. However, it is suggested that the level of significance be examined more carefully when more detailed individual country studies can be undertaken.

In Figure 3.7, the LGP types and patterns in the study region are depicted; in Table 3.5 the percent area by country is reported. In the west a year-round dry area covers large parts of Namibia and South Africa. In the central part of the study region the intermediate growing period is dominant. In the remaining area a normal growing period occurs. The two types of bimodal LGP patterns occur in the bimodal rainfall zones in northern parts of Tanzania. Only the first of the two growing periods was inventoried.

FIGURE 3.7
Length of growing period pattern



At the regional level, the dominant LGP type is normal, covering almost 60 percent of total land area, followed by intermediate (24.5 percent). The year-round dry type in Southern Africa is quite large (15 percent) with an area of more than 100 million ha.

TABLE 3.5
Extent of LGP pattern by country as percentage of total land area

Country	Unimodal		Bimodal	No LGP	All year-round humid	Total Land
	Normal	Intermediate	Normal-Normal	Dry		
	%	%	%	%	%	'000 ha
Angola	96.7	1.6	-	1.7	-	124,945
Botswana	1.0	86.0	-	13.0	-	57,178
Lesotho	17.0	83.0	-	-	-	2,968
Malawi	100.0	-	-	-	-	9,483
Mozambique	89.9	10.1	-	-	-	77,636
Namibia	7.4	43.1	-	49.5	-	82,083
South Africa	15.3	42.0	-	41.2	1.5	120,067
Swaziland	37.5	62.5	-	-	-	1,637
Tanzania	85.5	7.7	6.8	-	-	88,107
Zambia	100.0	-	-	-	-	73,638
Zimbabwe	66.3	28.9	-	4.8	-	38,318
Total	**59.3**	**24.5**	**0.9**	**15.0**	**0.3**	**676,060**

For the purpose of matching crops to LGP, information for both LGPs is required in order to estimate any additional agronomic yield potential. As an example, the relationship between the first LGP and second LGP for the bimodal type (b) LGP pattern in northern Tanzania is provided in Table 3.6.

TABLE 3.6
Relationship between the first LGP and the second LGP

First LGP (mapped)	Second LGP (not mapped)	Total LGP (First + Second)
90-119	50-74	140-193
120-149	75-98	195-247
150-179	99-122	249-299
180-209	123-146	303-355
210-215	147-150	357-365

3.2 SOIL RESOURCES INVENTORY

The soil resources inventory consists mainly of two components: soil information with various data concerning type, texture, mapping and so on; and landform information, including slope data. The soil information was extracted from the Harmonized World Soil Database (HWSD) (FAO *et al.*, 2008), which used as source for this specific area the Soil and Terrain (SOTER) digital database for Southern Africa (FAO/ISRIC, 2003).

3.2.1 Soil information

The HWSD provides information on standardized soil parameters for top- and subsoil for each soil unit composition (see details in Section 3.2.1.1). In particular the database contains information on dominant and associate soils (and their proportion); texture and phases; and physical and chemical characteristics of topsoil (0-30 cm) and subsoil (30-100 cm). For illustrative convenience the major soil group and the dominant texture in the study region is reported in Figure 3.8 and Figure 3.9. The information of the extent of the major soils is presented in Table 3.7.

FIGURE 3.8
Major soil

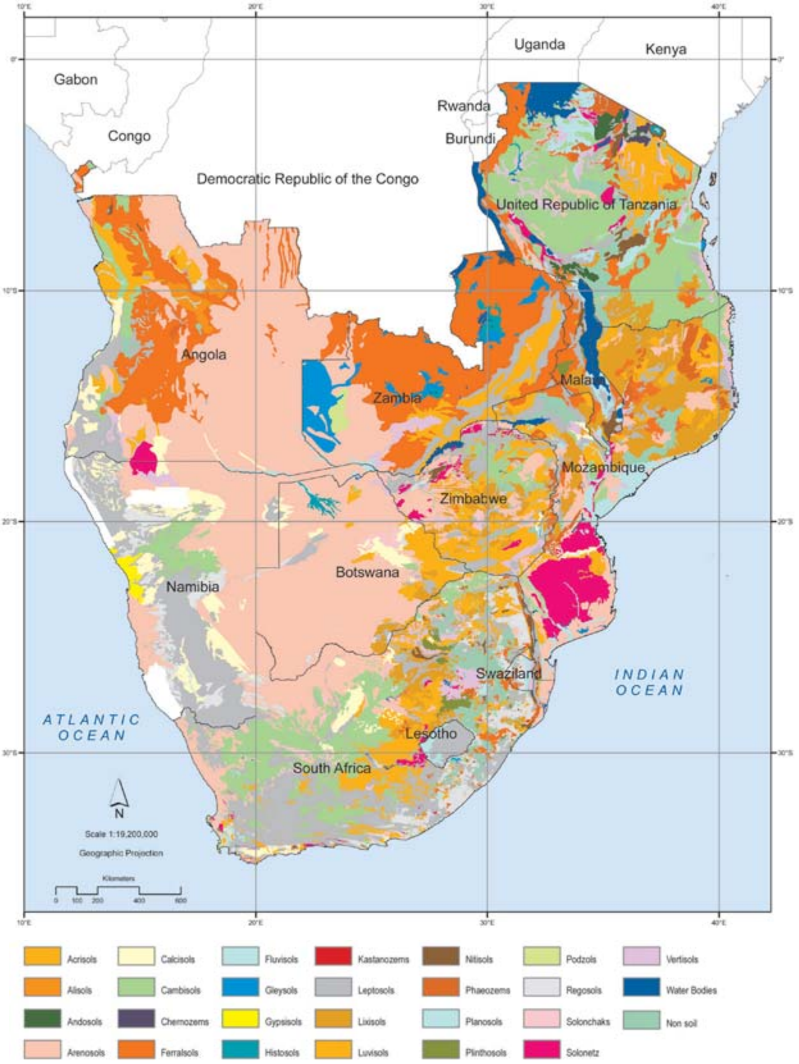
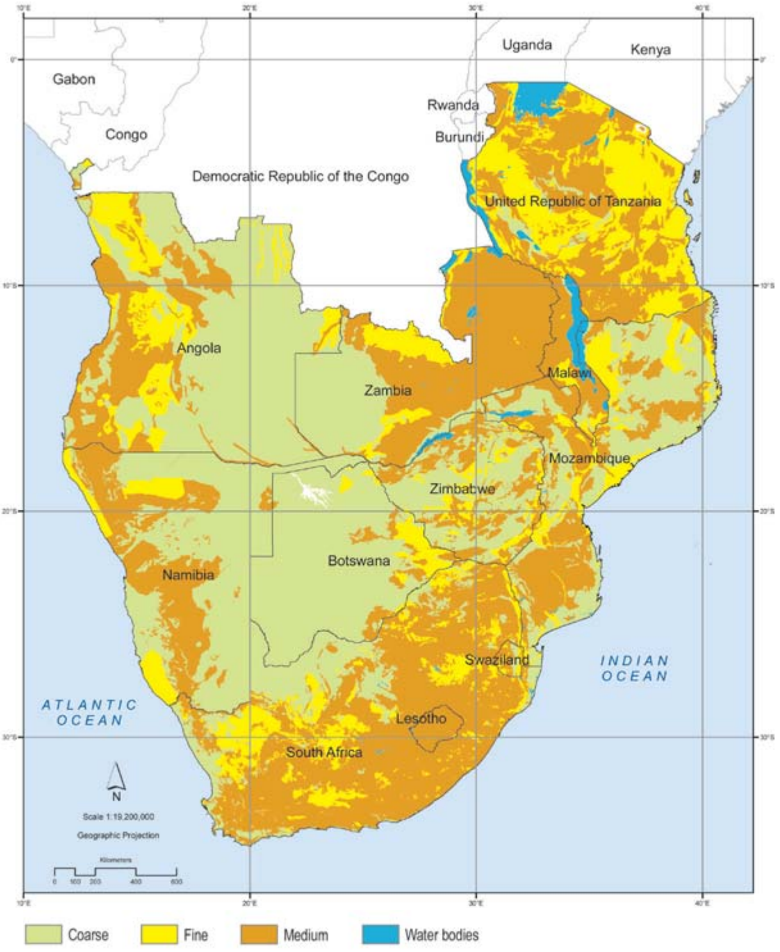


FIGURE 3.9
Dominant texture



The arenosol is the most frequent soil group in Angola, Botswana and Namibia; the leptsols is found dominantly in Lesotho, South Africa and Swaziland; the ferrosols in Malawi and Zambia; and the cambisols in Tanzania. In Mozambique the lixisols covers 24.4 percent of the country, and in Zimbabwe the dominant soil group, luvisols, covers 26.4 percent of the total land area. In the overall study region arenosol is the most frequent soil group with 28.5 percent of coverage, followed by leptsols (13.6), ferralsols (12.4) and cambisols (10.5).

Table 3.8 shows the extent of soil texture by country and in the region. In Angola, Botswana, Mozambique, Namibia and Zimbabwe, the predominant soil texture is coarse; in Lesotho, Malawi, South Africa, Swaziland, Tanzania and Zambia the main texture is medium. Fine texture does not predominate in

TABLE 3.7

Extent of major soils by country as percentage of total land area

Country / Major soil	Angola	Botswana	Lesotho	Malawi	Mozambique	Namibia	South Africa	Swaziland	Tanzania	Zambia	Zimbabwe	Total land by major soil	Share on total regional land
	%	%	%	%	%	%	%	%	%	%	%	‘000 ha	%
Acrisols	0.4	-	-	-	4.6	-	5.5	1.6	6.5	-	1.7	17,072	2.5
Alisols	2.0	-	-	-	-	-	-	-	-	-	-	2,517	0.4
Andosols	-	-	-	-	-	-	-	-	2.4	-	-	2,159	0.3
Arenosols	55.1	78.1	-	-	14.5	36.8	15.1	-	2.9	12.9	19.6	192,812	28.5
Calcisols	2.8	4.2	-	-	0.9	11.0	2.3	-	-	-	0.3	18,448	2.7
Cambisols	2.8	0.5	-	1.1	3.5	6.0	18.3	-	38.7	-	8.3	70,809	10.5
Chernozems	-	-	-	-	0.1	-	-	-	0.5	-	-	522	0.1
Ferralsols	22.6	-	0.7	32.7	4.4	-	1.2	10.1	10.9	50.7	1.3	83,736	12.4
Fluvisols	1.1	0.2	-	11.7	5.2	0.6	0.2	-	2.9	0.5	0.5	10,379	1.5
Gleysols	-	-	-	-	0.2	-	-	-	0.3	10.8	-	8,439	1.2
Gypsisols	-	-	-	-	-	1.7	-	-	-	-	-	1,361	0.2
Histosols	-	1.1	-	0.4	-	-	-	-	0.4	1.7	-	2,301	0.3
Kastanozems	-	-	-	-	-	-	0.1	-	-	-	-	73	0.0
Leptosols	6.1	3.2	77.7	21.3	7.9	27.2	24.3	25.1	7.0	8.4	19.5	91,617	13.6
Lixisols	0.2	2.6	0.1	15.5	24.4	-	4.8	-	3.6	0.1	11.9	35,769	5.3
Luvisols	5.1	8.2	-	-	11.2	-	12.3	0.1	8.3	10.1	26.4	59,391	8.8
Nitisols	0.1	-	-	8.5	-	-	0.8	2.6	1.7	0.3	0.7	3,937	0.6
Phaeozems	0.3	-	-	-	5.3	-	0.8	-	2.5	-	0.9	7,921	1.2
Planosols	-	-	21.3	-	2.1	-	0.7	20.1	3.2	-	-	6,163	0.9
Plinthosols	-	-	-	4.2	-	-	1.2	-	-	-	-	1,874	0.3
Podzols	-	-	-	-	-	-	-	-	-	1.7	-	1,305	0.2
Regosols	0.3	1.0	0.1	0.5	-	8.1	8.1	29.3	0.1	0.1	0.3	18,119	2.7
Solonchaks	-	0.4	-	-	-	-	1.1	-	0.3	-	1.0	2,128	0.3
Solonetz	0.6	-	-	-	13.1	0.8	0.9	-	2.2	-	4.3	16,245	2.4
Vertisols	0.5	0.5	-	1.3	1.9	0.8	2.3	11.0	5.3	2.3	3.1	13,781	2.0
Water Bodies	-	-	-	2.8	0.5	-	-	0.1	0.3	0.4	0.2	1,294	0.2
Unclassified	-	-	0.1	-	0.2	7.0	-	-	-	-	-	5,888	0.9
Total land area	**124,945**	**57,178**	**2,968**	**9,483**	**77,636**	**82,083**	**120,067**	**1,637**	**88,107**	**73,638**	**38,318**	**676,060**	

TABLE 3.8

Extent of soil texture classes by country as percentage of total land area

Country	Coarse	Medium	Fine	Total Land
	%	%	%	'000 ha
Angola	62.8	22.6	14.6	124,945
Botswana	83.0	9.2	7.8	57,178
Lesotho	0.3	53.3	46.4	2,968
Malawi	8.7	53.7	37.6	9,483
Mozambique	53.0	32.7	14.3	77,636
Namibia	64.2	35.1	0.7	82,083
South Africa	17.9	66.8	15.3	120,067
Swaziland	9.4	52.2	38.4	1,637
Tanzania	7.4	48.7	43.9	88,107
Zambia	32.6	49.0	18.4	73,638
Zimbabwe	51.0	34.1	14.9	38,318
Total	**43.2**	**39.5**	**17.2**	**676,060**

any country but the largest shares are in Lesotho and Tanzania. Overall, in the region the texture that occurs most frequently is coarse, covering 43.2 percent of the total area.

3.2.2 Soil mapping unit composition

At the exploratory level, a soil mapping unit only rarely comprises a single soil; usually it consists of one main soil with minor associates. When the various soils of a soil mapping unit occur in a recognisable geographical pattern in defined proportions, they constitute a soil association; if such a pattern is absent, they form a soil complex. Each soil mapping unit in the study region may contain a maximum of six soil types, with different proportions and characteristics. A detailed example of soil mapping unit composition is reported below. The soil mapping unit 28327 is in South Africa and the dominant soil group is Cambisols.

The unit contains four soil units, and detailed characteristics are reported in Table 3.9.

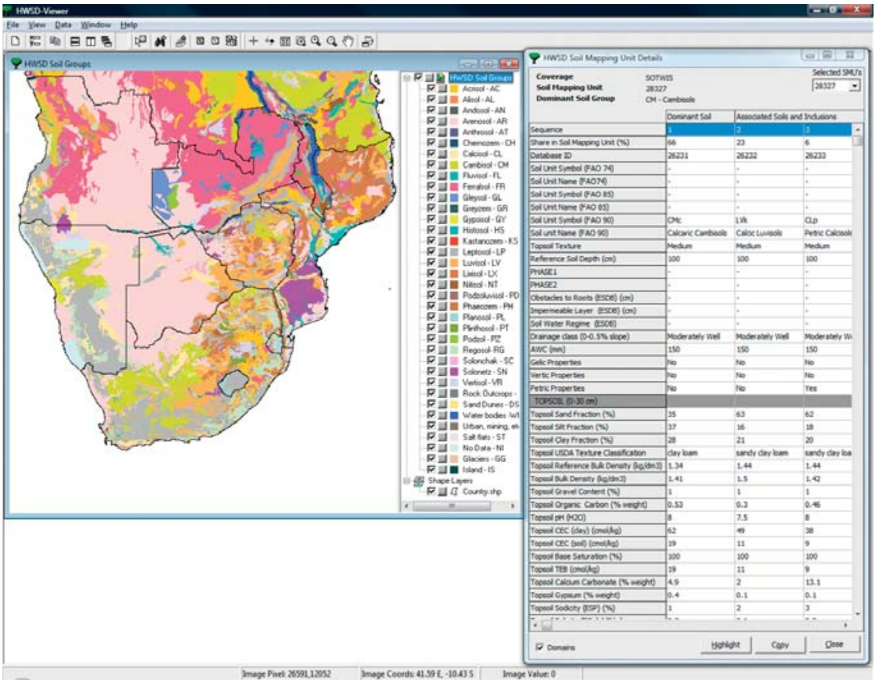
TABLE 3.9

Characteristics of the soil mapping unit 28327

Soil Unit Symbol (FAO 90)	Soil Unit Name (FAO 90)	Share in Soil Mapping Unit (%)	Topsoil Texture
CMc	Calcaric Cambisols	66	Medium
LVk	Calcic Luvisols	23	Medium
CLp	Petric Calcisols	6	Medium
GLe	Eutric Gleysols	5	Medium

FIGURE 3.10

HWSD viewer with soil mapping unit composition



Coverage SOTWIS
Soil Mapping Unit 28327
Dominant Soil Group CH - Cambisols

	Dominant Soil	Associated Soils and Inclusions	
Sequence	1	2	3
Share in Soil Mapping Unit (%)	66	23	6
Database ID	26231	26232	26233
Soil Unit Symbol (FAO 74)	-	-	-
Soil Unit Name (FAO74)	-	-	-
Soil Unit Symbol (FAO 85)	-	-	-
Soil Unit Name (FAO 85)	-	-	-
Soil Unit Symbol (FAO 90)	CMc	LVk	CLp
Soil unit Name (FAO 90)	Calcaric Cambisols	Calcic Luvisols	Petric Calcisols
Topsoil Texture	Medium	Medium	Medium
Reference Soil Depth (cm)	100	100	100
PHASE1	-	-	-
PHASE2	-	-	-
Obstacles to Roots (ESDB) (cm)	-	-	-
Impermeable Layer (ESDB) (cm)	-	-	-
Soil Water Regime (ESDB)	-	-	-
Drainage class (0-0.5% slope)	Moderately Well	Moderately Well	Moderately W
AWC (mm)	150	150	150
Gelic Properties	No	No	No
Vertic Properties	No	No	No
Petric Properties	No	No	Yes
TOPSOIL (0-30 cm)			
Topsoil Sand Fraction (%)	35	63	62
Topsoil Silt Fraction (%)	37	16	18
Topsoil Clay Fraction (%)	28	21	20
Topsoil USDA Texture Classification	clay loam	sandy clay loam	sandy clay loa
Topsoil Reference Bulk Density (kg/dm3)	1.34	1.44	1.44
Topsoil Bulk Density (kg/dm3)	1.41	1.5	1.42
Topsoil Gravel Content (%)	1	1	1
Topsoil Organic Carbon (% weight)	0.53	0.3	0.46
Topsoil pH (H2O)	8	7.5	8
Topsoil CEC (clay) (cmol/kg)	62	49	38
Topsoil CEC (soil) (cmol/kg)	19	11	9
Topsoil Base Saturation (%)	100	100	100
Topsoil TEB (cmol/kg)	19	11	9
Topsoil Calcium Carbonate (% weight)	4.9	2	13.1
Topsoil Gypsum (% weight)	0.4	0.1	0.1
Topsoil Sodicity (ESP) (%)	1	2	3

The Harmonised World Soil Database provides a free viewer to interrogate the soil information. Figure 3.10 shows the viewer and all the information related to the soil mapping unit 28327.

The productivity potential of different soil units within a soil mapping unit may consequently vary widely. The suitability of soil association (soil complex) for a specific use cannot be assessed without taking account of each individual soil unit within the association. This is the main reason why the map of the crop and land assessment for a specific crop is as a suitability index (as already described in Section 2.1), i.e. a weighted average of the suitability of each soil association.

3.2.3 Landform information

As indicated above, slope as a limiting factor for land workability, was used as proxy to define the landform of the terrain in the region. Slope information was derived from the Digital Elevation Model (DEM) database and is expressed in percentage. The DEM, at 90-meter resolution, is released by the Shuttle Radar Topography Mission (SRTM), a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

In the study region, the terrain is predominantly flat with a slope below five percent (Table 3.10, Figure 3.11). In South Africa, Lesotho and Swaziland, areas with a higher slope (>12 percent) can be found. The Drakensberg, or so-called Dragon Mountains, is the highest mountain range in Southern Africa, rising to 3482 metres.

FIGURE 3.11

Slope

In Malawi and Tanzania there are also areas with considerable slope (8–16 percent), representing the Kipengere Range, also known as the Livingstone Mountains, which lie in southwest Tanzania at the northern end of Lake Malawi.

TABLE 3.10

Extent of slope classes by country as percentage of total land area

Country	**0 - 2**	**2 - 5**	**5 - 8**	**8 - 12**	**12 - 16**	**16 - 23**	**23 - 30**	**> 30***	**Total Land**
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**'000 ha**
Angola	70.1	24.1	3.3	1.4	0.6	0.4	0.1	0.0	124,945
Botswana	99.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	57,178
Lesotho	5.9	17.9	19.5	23.9	16.2	13.0	2.9	0.7	2,968
Malawi	55.8	24.8	9.4	5.2	2.3	1.8	0.5	0.2	9,483
Mozambique	81.8	12.9	2.7	1.5	0.6	0.4	0.1	0.0	77,636
Namibia	79.4	14.4	3.4	1.7	0.6	0.4	0.1	0.0	82,083
South Africa	60.4	22.1	8.0	4.9	2.3	1.6	0.5	0.2	120,067
Swaziland	29.6	33.7	17.6	11.9	4.7	2.3	0.2	0.0	1,637
Tanzania	64.8	22.7	6.0	3.3	1.5	1.1	0.4	0.2	88,107
Zambia	84.0	12.1	2.3	1.0	0.4	0.2	0.0	0.0	73,638
Zimbabwe	73.6	19.1	4.2	1.9	0.7	0.4	0.1	0.0	38,318
Total	**73.7**	**17.6**	**4.3**	**2.3**	**1.1**	**0.7**	**0.2**	**0.1**	**676,060**

* the last three classes were aggregated because of the small area covered

CHAPTER 4

Assessing suitable land: The methodological framework and its implementation

The methodological framework for assessing suitable land is the Crop and Land Suitability Assessment (CLSA). CLSA is based on an agro-ecological zoning approach developed and used by FAO since 1978 (FAO, 1978; FAO, 1993). It is used to evaluate the suitability of a specific location for producing a particular crop under a defined agricultural production system based on the agro-climatic (i.e. thermal and moisture) conditions, and on the agro-edaphic (i.e. soil and landform) conditions.

A crop and land suitability assessment was conducted for the Southern Africa region for five bioenergy crops, namely cassava, sugarcane, sweet sorghum, sunflower and oil palm under rainfed production. The assessment was carried out for two production systems (tillage-based [TA] and conservation agriculture [CA]) and using two levels of inputs (low and high). The overall analysis was conducted for rainfed conditions, as this best describes the current agriculture management practice in the study region.

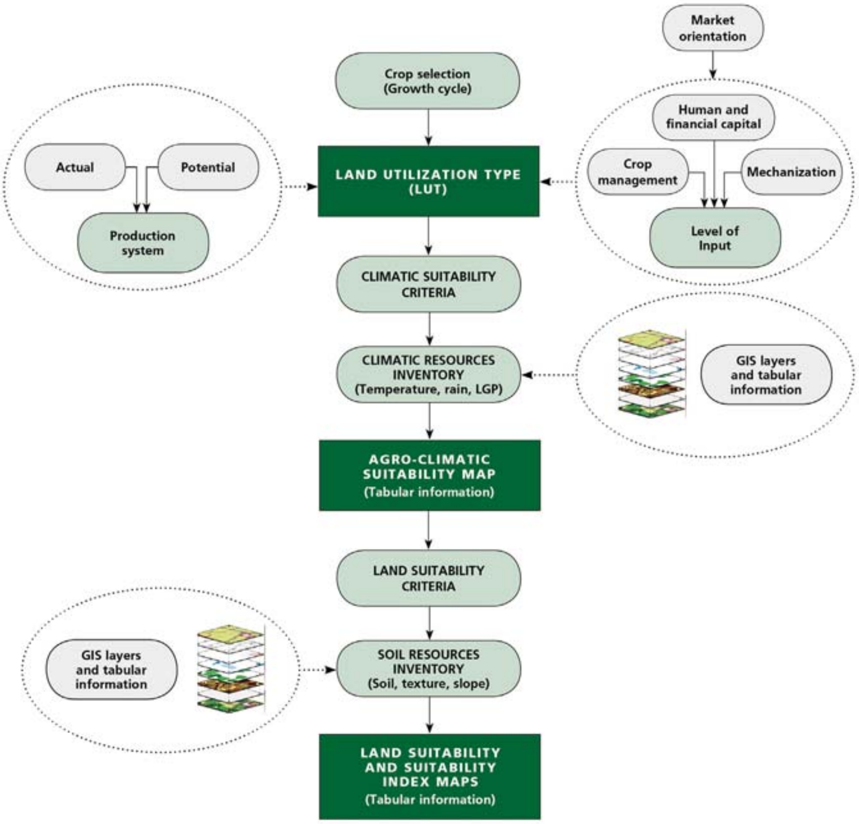
4.1 CROP AND LAND SUITABILITY ASSESSMENT

The suitability of a given portion of land is expressed as a percentage of the maximum attainable yield for each crop. The CLSA then evaluates the potential production for such areas. There are several steps to this analysis once the Land Resources Inventory described in Chapter 3 has been set up:

- define the Land Utilization Type (LUT), which is a combination of crop, production system and level of inputs;
- formulate the climatic and soil-related edaphic suitability assessment criteria for each LUT;
- apply LUT-specific agro-climatic criteria to derive crop agro-climatic suitability assuming no edaphic constraints; and
- apply LUT-specific agro-edaphic criteria to derive land suitability in terms of suitability classes and extent.

A detailed flowchart of the CLSA methodology can be found in Figure 4.1.

FIGURE 4.1
Crop and Land Suitability Assessment flowchart



The LUT definition is the crucial starting point of the analysis. The level of details to which the LUTs are defined is principally determined by the objectives of the study. More details in the LUT definition can provide information for estimating crop production costs.

The following factors are implied in the LUT definition:

- The description of an existing or anticipated agricultural production system in terms of crops, production techniques, and expected type and range of inputs.
- The identification of important factors that affect production potential, such as limits to mechanisation on sloping lands, or soil requirements for irrigation.
- The production scenarios to be modelled and the level at which production constraints are assumed to have been overcome in each scenario.

- The quantification of human and financial capital (labour, materials, capital, etc.) associated with various production scenarios, defined mainly on market orientation.

The LUT definition makes it possible to estimate the anticipated output or maximum attainable yield, which corresponds to a certain level of input. The maximum attainable yield is based on crop models and agronomic expertise as well as field surveys at farmer level (more details in Section 4.2). Geo-referenced and tabular information on climate and soil attributes should be compiled within the LUT definition in order to run the suitability analysis.

The agro-climatic and agro-edaphic criteria are formulated by interpreting climate and soil-related information in terms of any yield-reducing limiting factors or constraints to achieve the maximum attainable yield for a specific LUT.

The extent (in hectares) of LUT-specific agro-climatic suitability and land suitability (agro-climatic and agro-edaphic suitability combined) is expressed as one of the six suitability classes listed in Table 4.1.

TABLE 4.1
Agro-climatic, land suitability and suitability index classes

Code	Suitability Class	Percentage of potential constraint-free agronomically attainable yield
VS	Very suitable	80 – 100
S	Suitable	60 – 80
MS	Moderately suitable	40 – 60
mS	Marginally suitable	20 – 40
vmS	Very marginally suitable	> 0 – 20
NS	Not suitable	0

The extent of land suitability of an inventoried land unit is thus expressed in terms of a suitability index (SI), defined as the aggregate average land potential of a specific area location to achieve a certain percentage of the maximum attainable yield for a specific crop based on the combined agro-climatic and soil conditions. The SI is based on the same six suitability classes as above. An SI of “marginally suitable” (MS) for a particular inventoried thematic land unit does not mean that all the land in the unit is uniformly of the MS class, but rather that the average suitability of the different soil-climate units in the mapped land unit has an average class of MS.

The SI index reflects the suitability composition of a particular grid-cell of a soil mapping unit that has different shares of a number of soil types (more details in Section 3.2).

In this index, VS represents the portion of the grid-cell with attainable yields that are 80 percent or more of the maximum potential yield for the specified input scenario. Similarly, S, MS and mS represent portions of the grid-cell with attainable yields 60–80 percent, 40–60 percent, and 20–40 percent of the maximum potential yield, respectively. SI is calculated using the following equation:

$$SI = VS*0.9 + S*0.7 + MS*0.5 + mS*0.3 + vmS*0.1$$

where VS = very suitable, S = suitable, MS = moderately suitable, mS = marginally suitable, and vmS = very marginally suitable.

The methodology used is in its simplest form, in anticipation of the more detailed work to be done at the country level in the follow-up phase during which detailed information on climate, soil and crops would be studied. For example, as explained in the previous chapter, the climatic resources inventory is based on long-term monthly average data, rather a statistical analysis of historical daily or decadal data. At country level, the inventories of climate and soil would be more detailed, which would allow for a more accurate matching of crop climatic and edaphic requirements to the prevailing climatic and edaphic conditions.

4.2 CROPS AND LAND UTILIZATION TYPES

Five bioenergy crops were included in the assessment: cassava, sweet sorghum, sugarcane, sunflower and oil palm (Table 4.2).

TABLE 4.2
Crops included in the assessment

Crop and crop type	Scientific name	Growth cycle (days)
Cassava	*Manihot esculenta*	150 – 300
Sugar cane	*Saccharum officinarum*	210 – 365
Sweet sorghum (lowland)	*Sorghum bicolor var. sweet*	90 – 130
Sweet sorghum (highland)	*Sorghum bicolor var. Sweet*	120 – 300
Oil palm (tall and compact)	*Elaeis guineensis*	270 – 365
Sunflower	*Helianthus annuus*	100 – 120

A land utilization type (LUT) is defined as combinations of crop or crop types, production systems and input levels. An adequate description of any LUT information on the following items would ideally require:

- Produce and production system;
- Market orientation, including whether towards subsistence or commercial production;
- Capital and labour intensity;
- Size and configuration of land holding, including whether consolidated or fragmented;
- Technology employed, technical knowledge and attitude of land users;
- Land tenure, the legal or customary manner in which rights to land are held, by individuals or groups.

Four categories of reference LUTs were identified; their characteristics are summarised in Table 4.3. These are based on two production systems, tillage-based and Conservation Agriculture, at both a low and a high level of inputs and proper management. A total of 28 LUTs were thus defined in this crop and land suitability assessment.

TABLE 4.3
Attributes of Land Utilization Types

	Tillage-based Agriculture	**Conservation Agriculture**
Low input level	Tillage-based system, low input (TA-L) Subsistence-type production system with low capital input Use of traditional or modern cultivars of crops Tilling uses hand labour and traditional tools only Tillage-based cultivation in rotation with bush, often referred to as 'slash and burn' Excludes the use of: Synthetic mineral fertilizer or other agrochemicals Large-scale conservation measures	Conservation Agriculture, low input (CA-L) Subsistence-type production system with low capital input Use of traditional or modern cultivars of crops Hand labour only, traditional or improved tools for seeding or planting with minimum soil disturbance Crops are planted in rotation with other crops (including legumes) to maintain pest control, soil fertility and productive capacity Residues are retained as much as possible for "*in situ*" composting Excludes the use of: Synthetic mineral fertilizer or other agrochemicals Large-scale conservation measures Bush fallows in the rotations and 'slash and burn'
High input level	Tillage-based system, high input (TA-H) Capital-intensive management practices with high-level of input Full use of the most productive and adapted modern cultivars of crops Complete mechanization with plough-based intensive tillage Application of high levels of agrochemicals Full soil conservation measures Excludes the use of: Attention to protect or enhance ecosystem services such as increasing carbon sequestration and soil organic matter build-up, or improving water resource quantity and quality	Conservation Agriculture, high input (CA-H) Capital-intensive management practices with high-level input Full use of the most productive and adapted modern cultivars of crops Complete mechanization with no tillage Use of optimum levels of agro-chemicals 'Permanent' organic-matter soil cover from crop residues and cover crops Cover crops with legumes in the rotations Full attention to ecosystem services to keep production, environmental costs and product price competitively low and productivity and returns high. Excludes the use of: Tillage or mechanical soil disturbance

4.3 AGRO-CLIMATIC CROP SUITABILITY

To enable crops to be matched to climatic conditions, the climatic resources inventory of the study region was compiled to permit the interpretation of the climatic resources in terms of their suitability for production of crops (see Ch. 3). The appropriate climatic adaptability attributes of the crop determine which parameters must be taken into account in the compilation of the climatic inventory. The climatic adaptability attributes of crops form the basis of defining the crop climatic requirements, and are outlined in the following section. Collection of data on the climatic adaptability of crops was begun in 1977 for FAO agro-ecological zones project (Kassam *et al.*, 1977; FAO, 1978-81). Since 1991, the data has been housed within the FAO ECOCROP database[1].

4.3.1 Crop climatic adaptability and requirements

The photosynthetic and phenological requirements of crops both affect yield. The rate of crop photosynthesis and growth are related to the assimilation pathway and its response to temperature and radiation. However, the phenological climatic requirements, which must be met, are not specific to a photosynthetic pathway.

As described in FAO agro-ecological zones methodology (Kassam *et al.*, 1977; FAO, 1978-81), crops are classified into climatic adaptability groups according to their fairly distinct photosynthesis characteristics. Each group comprises crops of “similar ability” in relation to potential photosynthesis, and the differences between land within groups in the response of photosynthesis to temperature and radiation determine crop-specific biomass productivity when climatic phenological requirements are met.

Crop adaptability groups and their characteristic average photosynthesis response to temperature and radiation are presented in Table 4.4. Wheat, barley, oat, rapeseed and white potato have a C3 photosynthesis pathway, belong to group I and are adapted to grow under cool conditions (< 20 °C mean daily temperature). Sunflower, sweet potato, cassava, castor, jatropha, pongamia and oil palm have a C3 photosynthesis pathway, belong to group II and are adapted to grow under warm conditions (> 20 °C) with a potential rate of photosynthesis that is higher than in group I crops. Crops in group III (lowland sweet sorghum, lowland maize and sugarcane) have a C4 photosynthesis pathway and are adapted to grow under warm conditions (> 20 °C), but with a potential rate of photosynthesis that is higher than in group II crops. Crops in group IV (highland sweet sorghum and highland maize) have a C4 photosynthesis pathway and are adapted to grow under cool conditions (<20°C) with a potential rate of photosynthesis similar to that of group III crops.

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[1] ECOCROP contains information primarily about climate and soil requirements and uses of plant species, but it also provides a range of other information, such as brief description of the species, common names in different languages and possible yields. ECOCROP makes it possible to identify a suitable crop for a specified environment, identify a crop with a specific habit of growth or for a defined use, and look up the environmental requirements and uses of a given crop. Over 2100 species are now covered. ECOCROP is also a tool for recording, organising, comparing and using studies on crop response to environmental and management factors see http://ecocrop.fao.org/ecocrop/srv/en/home.

TABLE 4.4

Average photosynthesis response of individual leaves of four groups of possible bioenergy crops to radiation and temperature

Characteristics	Crop adaptability group			
	I	II	III	IV
Photosynthesis pathway	C3	C3	C4	C4
Rate of photosynthesis at light saturation at optimum temperature (mg CO2dm-2h-1)	20 – 30	40 – 50	> 70	> 70
Optimum temperature (°C) for maximum photosynthesis	15 – 20	25 – 30	30 – 35	20 – 30
Radiation intensity of maximum photosynthesis (cal cm-2min-1)	0.2 – 0.6	0.3 – 0.8	> 1.0	> 1.0
Main crops	Wheat Barley Oat Rapeseed Sugar beet White potato	Sunflower Sweet potato Cassava Castor Jatropha Pongamia Oil palm	Lowland maize Lowland sweet sorghum Sugarcane	Highland maize Highland sweet sorghum

The time required to produce crop yield depends on the phenological constraints on the use of time available in the growing period, and the location of yield in the plant (e.g. seed, leaf, stem, and root) has an important influence. Temperature has a rate controlling/limiting effect on growth, and it may influence the growth of a specific plant part and accumulation of yield if located therein. For example, in wheat, barley and oat, cool night temperatures are required for tillering, but the optimal temperatures at the time of flowering and subsequent yield formation are higher. Similarly, optimal temperatures for growth in sugarcane are higher than 20 °C, but during the ripening period and because the yield is located in the stem, a lower temperature in the range 10-20 °C is required for concentration of the proper type of sugar within the cane. On the other hand, optimal temperatures for growth, development and yield formation in sunflower, sweet potato and cassava are higher than 20°C and most of the specific temperature requirements are also met when temperatures are optimal for photosynthesis and growth.

The attributes that are helpful in assessing the climatic adaptability of the selected crops in the matching exercise are given in Table 4.5. Similar information regarding the other crops has been made available by FAO (1978), Kassam (1980) and in the ECOCROP database.

TABLE 4.5
Climatic adaptability attributes of crops

Attributes	Cassava	Sugarcane	Sweet sorghum (High and lowland)	Oil palm (Tall and compact)	Sunflower
Species	Manihot esculenta	Saccharum officinarum	Sorghum bicolor var. sweet	Elaeis guineensis	Helianthus annuus
Photosynthesis pathway	C3	C4	C4	C3	C3
Crop adaptability group	II	III	III	II	II
Days of maturity*	180 – 270 (EC) 270 – 365 (LC)	270 – 365	90 – 110 (EC) 120 – 130 (MEC) 140 – 240 (LC)	330 – 365	100 – 120 (UBC, EC) 130 – 160 (BRC, LC)
Harvested part	Tuber	Stem	Seed	Seed	Seed
Main product	Tuber, Starch	Sugar	Grain (Cereal)	Oil, cake	Oil
Growth habit	Indeterminate	Determinate	Determinate	Indeterminate	Determinate
Life-span					
Natural	Short-term perennial	Perennial	Annual	Perennial	Annual
Cultivated	Annual	Annual/ Biennial	Annual	Perennial	Annual
Yield					
Location	Root	Stem	Terminal inflorescence	Lateral inflorescence	Terminal inflorescence
Formation period	Two thirds crop's life	Two thirds crop's life	Last third period in crop's life	Two thirds crop's life	Last third period in crop's life
Thermal zone	Tropical lowland, humid and seasonally arid	Tropical lowland, humid; Subtropical summer rainfall, T > 20°C	Tropical lowland, seasonally arid; Subtropical summer rainfall, T > 20°C	Tropical lowland, humid	Tropical lowland, seasonally arid; Subtropical summer rainfall, T > 20°C

* Days of maturity:

EC = Early cultivar
MEC = Medium cultivar
LC = Late cultivar
BRC = Branched cultivar
UBC = Unbranched cultivar

To summarise from the table:

Cassava (C3-species, group II) is an annual with botanically indeterminate growth habits. The yield is located in the root, and the crop yield formation period is most or all of the growth cycle period. Climatic adaptability attributes qualify it to be considered for matching in tropical humid and seasonally arid lowland areas with altitudes under 1500m.

Sugarcane (C4-species, group III) is an annual/biennial with botanically determinate growth habits. The yield is located in the stem, and the crop yield formation period is most or all of the growth cycle period. Climatic adaptability attributes qualify it to be considered for matching in tropical humid lowland areas (with precipitation greater or equal to evapotranspiration for seven to twelve months) and subtropical areas with summer rainfall and warm growing period with mean temperature higher than 20°C.

Sweet sorghum (C4-species, group III), both highland and lowland species, is an annual with botanically determinate growth habits. The yield is located in terminal inflorescences, and the crop yield formation period is the last third of growth cycle. Climatic adaptability attributes qualify it to be considered for matching in tropical humid lowland areas (with precipitation greater or equal to evapotranspiration for 7–12 months) and subtropical areas with summer rainfall and warm growing period with mean temperature higher than 20 °C.

Oil palm (C3-species, group II), both tall and compact species, is a perennial with botanically indeterminate growth habits. The yield is located in lateral inflorescences, and the crop yield formation period covers two-thirds of the annual growth cycle. Climatic adaptability attributes qualify it to be considered for matching in tropical humid lowland areas with precipitation higher than or equal to evapotranspiration for 7–12 months.

Sunflower (C3-species, group II) is an annual with botanically determinate growth habits. The yield is located in terminal inflorescences, and the crop yield formation period is the last third of the growth cycle. Climatic adaptability attributes qualify it to be considered for matching in tropical lowland areas seasonally arid with precipitation higher than or equal to evapotranspiration for less than seven months.

4.3.2 Maximum agronomically attainable yield

The maximum attainable (potential) yield of a specific crop (Ymp) is defined as the harvested yield of a high-producing variety which is well-adapted to the given growing environment, including the time available to reach maturity and under conditions where water, nutrients and pests and disease do not limit yield. Climatic factors which determine Ymp are temperature, solar radiation and the length of total growing season in addition to any specific temperature and day-length requirements for crop development. Temperature determines the rate of crop development and consequently affects the length of total growing period required for the crop to form yield. Crop growth and yield are affected by total radiation received during the growing period.

It is generally asserted that the maximum yield level of a crop is determined primarily by its genetic characteristics (G) combined with how well the crop is adapted to the prevailing environment (E). However, G and E factors and processes are numerous, and not only do they interact among and between themselves, but there are also other agro-ecosystem components including above- and below-ground agro-biodiversity, soil organic matter, organic mulch presence or absence, soil microorganisms and meso-fauna, soil biological processes, soil structure, porosity and aeration, etc. – all of which affect soil moisture, soil nutrients and pest dynamics. Thus, maximum "constraint-free" agronomically attainable yield level and the factor efficiencies with which it can be achieved (i.e. factor and total productivity) is the result of the production system paradigm (e.g. TA vs. CA approach) and the input and management level used to manipulate the various agronomic elements of the broader set of G x E interactions. So, while mineral fertiliser is an important input, its efficiency of utilization will also depend on soil health and biological parameters and how well they are managed in space and time under which type of production systems; the same holds for water input.

Thus, the maximum agronomically attainable yield under constraint-free conditions is different for crops produced under a TA "Green Revolution" system compared with same crops produced under a CA system, the latter being higher, depending on the yield level. For the purpose of this regional assessment, a CA approach at low-input level is assumed to provide extra potential yield advantages of 35, 30 and 25 percent in the semi-arid, sub-humid and humid zones respectively, and at high-input level of 25, 20 and 15 percent respectively.

Maximum attainable yields (and associated starch, sugar and oil content) considered for this analysis (subject to further refinement based on country-specific information) is shown in Table 4.6 for the five crops at the low- and high-input level under TA and CA-based systems. The low input level yields are assumed to be some 25 percent of the yield level at the respective high levels. The yield figures for crops produced under conventional systems were derived from the recent AEZ studies and yield databases. Those for CA were derived from empirical results, that are increasingly becoming available as a result of CA adoption in the region, and from expert knowledge.

4.3.3 Thermal zone crop suitability

Thermal zone suitability is determined according to the adequacy of prevailing temperatures during the growing period for crop growth, development and yield formation. Any eventual specific temperature requirement for crop development must also be taken into account. In the case of highland sweet sorghum, for example, the length of the crop growth cycle is longer at cooler temperatures, as described below.

The association between crop growth cycles and thermal zones in Southern Africa region for the selected crop types is presented in Table 4.7. In general, in the growth cycle length (number of days to maturity) for sorghum, there are generally about 20 more days required for maturation for each 100 m increase in altitude above 1500 m, or for each 0.5 °C decrease in mean temperature from 20 °C. The 20-day extension in maturity is composed of some 5–6 days delay in flowering (silking/anthesis) and some 14–15 days extension in the grain filling phase or time taken to reach black layer physiological maturity. For example, 110 and 130 days to maturity correspond respectively to 63 and 69 days to tasseling or heading, 73 and 79 days to silking or anthesis, and 110 and 130 days to physiological maturity.

TABLE 4.6

Agronomically attainable reference potential yields, starch, sugar and oil content, comparison between Tillage-based Agriculture (TA) and Conservation Agriculture (CA)

Production system / Crop	Tillage-based Agriculture Low level of input	Tillage-based Agriculture High level of input	Conservation Agriculture Low level of input	Conservation Agriculture High level of input
Cassava	Ton/ha	Ton/ha	Ton/ha	Ton/ha
Fresh root	12.5	50.0	15.6	57.5
Dry root	5.0	20.0	6.2	23.0
Starch	3.7	15.0	4.7	17.2
Sugar cane				
Fresh cane	30.0	121.0	37.0	139.0
Sugar	3.0	12.1	3.7	13.9
Sweet sorghum (lowland)				
Grain	1.5	6.0	2.0	7.5
Fresh cane	12.5	50.0	20.0	62.5
Juice	6.3	25.0	10.0	31.3
Sugar	0.9	3.8	1.5	4.7
Sweet sorghum (highland)				
Grain	2.2	9.0	2.9	10.8
Fresh cane	20.0	80.0	26.0	100.0
Juice	10.0	40.0	13.0	50.0
Sugar	1.5	6.0	2.0	7.5
Oil palm (tall)				
Fresh fruit	7.5	30.0	9.4	34.5
Oil	2.2	9.0	2.8	10.3
Oil palm (compact)				
Fresh fruit	8.2	33.0	10.2	37.9
Oil	2.5	9.9	3.1	11.4
Sunflower				
Seed	1.2	5.0	1.7	6.2
Oil	0.5	2.3	0.8	2.8

TABLE 4.7

Crop growth cycle and thermal regime association

Crop and crop type	Growth cycle	Thermal regime
	days	range (°C)
Cassava	150 – 300	> 17.5
Sugar cane	210 – 365	> 17.5
Sweet sorghum (lowland)	90 – 130	> 20.0
Sweet sorghum (highland)	120 – 200	17.5 – 20.0
	200 – 300	15.0 – 17.5
Oil palm (tall)	270 – 365	> 22.5
Oil palm (compact)	270 – 365	> 20.0
Sunflower	100 – 120	> 20.0

For sorghum, mean temperatures below 15 °C were considered too low for normal production because of the very severe problems with seed set and maturation.

TABLE 4.8
Thermal zone suitability ratings

Thermal zones / Crops	T1	T2	T3	T4	T5	T6	T7	T8-T11
	>25.0	22.5-25.0	21.25-22.5	20.0-21.25	18.75-20.0	17.5-18.75	15.0-17.5	<15.0
Cassava	S1	S1	S2	S3	S4	S4	N	N
Sugarcane	S1	S1	S2	S3	S4	S4	N	N
Sweet sorghum (L)	S1	S1	S1	S2	S3	N	N	N
Sweet sorghum (H)	N	N	S2	S1	S1	S2	S4	N
Oil palm (T)	S1	S2	S3	S4	N	N	N	N
Oil palm (C)	S1	S1	S2	S3	S4	N	N	N
Sunflower	S1	S1	S1	S2	S3	S3	S4	N

The crop thermal zone suitability ratings for each crop type are presented in Table 4.8. Five thermal suitability classes are employed (i.e. SI, S2, S3, S4 and N), and the ratings apply to both production systems at two levels of inputs: where temperature requirements are fully met, the thermal zone is adjudged S1; where requirements are sub-optimal the zone is adjudged S2, S3 or S4; where requirements are not met, the zone is adjudged as N (not suitable).

A rating of S1 indicates that the temperature conditions for growth/yield physiology and phenological development are optimal and that it is possible to achieve the maximum attainable agronomic yield potential if there are no additional climatic and/or edaphic (including landform) limitations. Ratings of S2, S3 and S4 indicate that temperature conditions for growth and development are sub-optimal and that yield potentials will be lower than maximum, i.e. 75, 50 and 25 percent, respectively, for thermal zones with suitability rating class S2, S3 and S4. A rating class of N indicates that temperatures in the thermal zone are not considered suitable for production of the crop under consideration.

4.3.4 LGP zone crop suitability

Yield losses in a rainfed crop due to agro-climatic constraints can be considered to be governed mainly by the condition of how well the length of the normal growth cycle (from sowing to physiological maturity) of a specific crop fits into the available length of growing period. When the growing period is shorter than the growth cycle of the crop, there is a loss in yield. Yield losses can also occur when the length of growing period is much longer than the length of growth cycle. With some crops, using long-duration cultivars can reduce part of these losses.

The degree of water stress during the growing period can affect (a) crop growth or (b) yield formation and quality of produce. Effect *b* in some crops can be more severe than effect *a*, particularly in crops where the yield is a reproductive part (e.g. in grain crops) and yield formation depends on the sensitivity of floral parts and fruit set to water stress (e.g. silk drying in maize).

The yield losses due to the length of growing period for the selected LUTs are expressed in percentage and reported in Table 4.9.

TABLE 4.9

Percentage of maximum attainable yield by LGP classes*

LGP Crops	0-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-365
Cassava										
TA	0% (NS)	5% (vmS)	11% (vmS)	26% (mS)	64% (S)	80% (S)	88% (VS)	92% (VS)	100% (VS)	54% (MS)
CA	0% (NS)	7% (vmS)	18% (vmS)	45% (MS)	72% (S)	84% (VS)	90% (VS)	100% (VS)	100% (VS)	54% (MS)
Sugarcane										
TA	0% (NS)	0% (NS)	0% (NS)	0% (NS)	0% (NS)	38% (mS)	54% (MS)	70% (S)	85% (VS)	100% (VS)
CA	0% (NS)	0% (NS)	0% (NS)	0% (NS)	19% (vmS)	46% (MS)	77% (S)	85% (VS)	85% (VS)	100% (VS)
Sweet sorghum (lowland)										
TA	0% (NS)	41% (MS)	75% (S)	100% (VS)	98% (VS)	53% (MS)	23% (mS)	18% (vmS)	12% (vmS)	12% (vmS)
CA	0% (NS)	58% (MS)	87% (VS)	100% (VS)	98% (S)	53% (MS)	23% (mS)	12% (vmS)	12% (vmS)	12% (vmS)
Sweet sorghum (highland)										
TA	0% (NS)	2% (vmS)	7% (vmS)	33% (mS)	66% (S)	100% (VS)	75% (S)	38% (mS)	19% (vmS)	13% (vmS)
CA	0% (NS)	4% (vmS)	20% (vmS)	49% (MS)	83% (VS)	100% (VS)	75% (S)	38% (mS)	19% (vmS)	13% (vmS)
Oil palm (tall)										
TA	0% (NS)	0% (NS)	0% (NS)	0% (NS)	0% NS)	6% (vmS)	18% (vmS)	44% (MS)	62% (S)	93% (VS)
CA	0% (NS)	0% (NS)	0% (NS)	0% (NS)	3% (vmS)	12% (vmS)	44% (MS)	62% (S)	62% (S)	93% (VS)
Oil palm (compact)										
TA	0% (NS)	0% (NS)	0% (NS)	0% (NS)	0% (NS)	6% (vmS)	18% (vmS)	59% (MS)	82% (VS)	100% (VS)
CA	0% (NS)	0% (NS)	0% (NS)	0% (NS)	3% (vmS)	12% (vmS)	59% (MS)	82% (VS)	82% (VS)	100% (VS)
Sunflower										
TA	0% (NS)	41% (MS)	75% (S)	100% (VS)	98% (VS)	53% (MS)	23% (mS)	18% (vmS)	12% (vmS)	12% (vmS)
CA	0% (NS)	75% (S)	87% (VS)	100% (VS)	98% (VS)	53% (MS)	23% (mS)	18% (vmS)	12% (vmS)	12% (vmS)

* See Chapter 4, Table 4.1 for full explanation of the agro-climatic, land suitability and suitability index classes.

** VS = Very suitable; S = Suitable; MS = Moderately suitable; mS = Marginally suitable; vmS = Very marginally suitable; NS = Not suitable

The yield- and quality-reducing factors of pests, diseases and weeds comprise factors that operate indirectly through climatic conditions. To assess the agro-climatic constraints of the pest, disease and weed complex, it is convenient to separate the effects on yield that operate through loss in crop growth (e.g. pests and diseases affecting vegetative parts in grain crops) from the effects on yield that operate directly on yield formation and produce quality (e.g. grain mould in sorghum affecting both yield and grain quality).

Finally, the soil moisture can pose a further constraint to the farming operations that include land preparation, sowing cultivation and crop protection during crop growth and harvesting. These constraints are essentially workability constraints, e.g. operational problems of mechanical sowing and harvesting under wet conditions, problems of handling wet produce, problems of effectively applying biocides to crop under wet conditions. These constraints can cause direct losses of quality produce and/or reduce the suitability of a specific area for a given crop from the point of view of how effectively operations related to cultural practices and produce handling can be conducted at a given level of inputs.

The above-mentioned constraints are complex and dynamic and their interrelations make it extremely difficult to quantitatively assess their role and effect.

4.3.5 Crop LGP suitability adjustment due to LGP pattern

As explained in Chapter 3, in the case of type (b) LGP pattern (see Figure 3.6 and Table 3.6), both growing periods are normal and greater than 75 days, and have crop growth potentials which should be taken into account in crop and land suitability assessments; Table 3.6 showed the lengths of the two LGPs in the bimodal zone with type (b) LGP.

Based on this information, yields were adjusted for crops which could take advantage of the second growing period; the adjusted yield potentials for cassava, sugarcane and oil palm as well as for the first and second LGPs for sweet sorghum and sunflower are presented in Table 4.10.

TABLE 4.10

LGP pattern normal-normal with yields adjusted for second growing period

LGP **Crops**	**0-90**	**90-120**	**120-150**	**150-180**	**180-210**	**> 210**
Cassava						
TA	0% (NS)	5% (vmS)	36% (mS)	45% (MS)	75% (S)	80% (S)
CA	0% (NS)	8% (vmS)	42% (MS)	72% (S)	75% (S)	80% (S)
Sugarcane						
TA	0% (NS)	0% (NS)	8% (vmS)	31% (mS)	69% (S)	75% (S)
CA	0% (NS)	0% (NS)	30% (mS)	64% (S)	100% (VS)	100% (VS)
Sweet sorghum (lowland)						
TA	0% (NS)	1 crop 41% (MS)	2 crops 1st (75%) (S) 2nd (41%) (MS)	2 crops 1st (100%) (S) 2nd (41%) (MS)	2 crops 1st (98%) (VS) 2nd (75%) (S)	2 crops 1st (53%) (MS) 2nd (75%) (S)
CA	0% (NS)	1 crop 73% (S)	2 crops 1st (80%) (S) 2nd (41%) (MS)	2 crops 1st (100%) (VS) 2nd (58%) (MS)	2 crops 1st (98%) (VS) 2nd (87%) (VS)	2 crops 1st (53%) (MS) 2nd (87%) (VS)
Sweet sorghum (highland)						
TA	0% (NS)	1 crop 2% (vmS)	1 crop 7% (vmS)	2 crops 1st (33%) (mS) 2nd (2%) (vmS)	2 crops 1st (50%) (S) 2nd (7%) (vmS)	2 crops 1st (50%) (S) 2nd (7%) (vmS)
CA	0% (NS)	1 crop 4% (vmS)	2 crops 1st (20%) (vmS) 2nd (4%) (vmS)	2 crops 1st (49%) (MS) 2nd (12%) (vmS)	2 crops 1st (62%) (S) 2nd (20%) (vmS)	2 crops 1st (62%) (S) 2nd (20%) (vmS)
Oil palm (tall)						
TA	0% (NS)	0% (NS)	0% (NS)	19% (vmS)	58% (MS)	70% (S)
CA	0% (NS)	0% (NS)	28% (MS)	62% (MS)	96% (VS)	100% (VS)
Oil palm (compact)						
TA	0% (NS)	0% (NS)	0% (NS)	16% (vmS)	68% (S)	77% (S)
CA	0% (NS)	0% (NS)	35% (mS)	82% (VS)	100% (VS)	100% (VS)
Sunflower						
TA	0% (NS)	41% (MS)	75% (S)	75% (S)	49% (MS)	27% (mS)
CA	0% (NS)	81% (VS)	2 crops 1st (87%) (VS) 2nd (41%) (MS)	2 crops 1st (100%) (VS) 2nd (75%) (S)	2 crops 1st (98%) (VS) 2nd (87%) (VS)	2 crops 1st (53%) (MS) 2nd (87%) (VS)

*VS = Very suitable; S = Suitable; MS = Moderately suitable; mS = Marginally suitable; vmS = Very marginally suitable; NS = Not suitable

4.3.6 Crop LGP suitability adjustment in intermediate LGP zones

The advantages of CA in terms of better moisture quantity for normal LGP were incorporated into the LGP rules for normal LGP zones as given in Table 4.9.

For intermediate LGP zones, an additional percentage reduction in the agronomic potential yields for the five crops under TA and CA systems with low and high inputs were made based on the following assumed rule:

- For TA, one-half (50 percent) of crop water requirement is assumed not to be met in intermediate LGP zones;
- For CA, one-third (33 percent) of crop water requirement is assumed not to be met in intermediate LGP zones.

The effect of the above short fall in water requirement was estimated in part using the yield response factor (ky) values from Doorenbos and Kassam (1979), and the percent reductions in yields shown in Table 4.11.

TABLE 4.11
Yield reduction applied to intermediate LGP zones for tillage-based agriculture (TA) and conservation agriculture (CA)

Crop	Seasonal ky	TA-Low	TA-High	CA-Low	CA-High
		%	%	%	%
Cassava	1.0*	50	50	34	34
Sugarcane	1.2	60	60	41	41
Sweet Sorghum	0.9	45	45	31	31
Oil palm	1.0*	50	50	34	34
Sunflower	0.95	48	48	32	32

* Assumed ky (yield-response factor) values

4.4 AGRO-EDAPHIC CROP SUITABILITY

The edaphic suitability assessment is input-specific and for this preliminary assessment was based on:

(i) matching the soil requirements of crop with the soil conditions of the soil units described in the soil inventory (soil unit evaluation; see Chapter 3); and
(ii) modification of the soil unit evaluation by limitation imposed by texture and slope.

As a medium in which roots grow and as a reservoir for water and nutrients on which plants continuously draw during their life cycle, the soil is a natural resource and a valuable economic asset requiring protection, conservation and improvement through good husbandry. The adequate agricultural exploitation of the climatic potential and sustained maintenance of productivity largely depends on soil fertility and management of soil on an ecologically sound basis. Soil fertility is the ability of the soil to supply nutrients and water to enable crops to maximize the climatic resources of a given location, and it is determined by the physical, chemical, hydrological and biological properties of a given soil, the understanding of which is essential to the effective utilization of climate and crop resources for optimal production.

In order to assess suitability of soils for crop production, soil requirements of crops must be known. Further, these requirements must be understood within the context of limitations imposed by landform and other features, which do not form a part of soil but may have a significant influence on the use that can be made of the soil. Crop requirements in relation to soil internal and external conditions have been explained by FAO (1978-81; 1991).

The crop production system employed (i.e. TA vs. CA) will significantly affect all soil properties and productive capacity. The effect of the production system on soil moisture or hydrological conditions was taken into account in the LGP suitability assessment (Table 4.9). The effect of production system on other aspects of soil, specifically soil health, and therefore its productive capacity, was taken into account by assuming that when the soil suitability class under TA production system was S2, under CA the suitability class was S1. Where soil suitability was rated as N under TA, it was also rated as N under CA. In reality, this may not hold everywhere, since soil quality parameters (e.g. soil structure and porosity, soil organic matter content, soil moisture content and moisture holding capacity, CEC and soil nutrient availability and nutrient holding capacity, drainage, soil infiltration, etc.), and therefore soil productive capacity and crop suitability, improve significantly under CA.

4.4.1 Soil unit evaluation

The soil unit evaluation is expressed in terms of suitability ratings based on how far the soil conditions of a soil unit meet the crop requirements under a specified level of inputs. The three basic suitability classes are: S1, very suitable or suitable; S2, moderately or marginally suitable; N, not suitable. A rating of S1 indicates that there are no or only minor limitations to production of the crop, provided climatic conditions are suitable. The rating of S2 indicates that soil limitations are such that they would markedly affect production of the crop, yet not to the extent of making the land completely unsuitable for that crop. The N rating means that the soil limitations appear to be so severe that crop production is not possible or is at best very limited. An example of soil unit ratings for sunflower for two production systems at two input levels each are presented in Annex 3.

4.4.2 Texture limitations

Soil unit ratings apply if there are no additional limitations imposed by texture. Modifications are required where limitations are imposed by texture.

Soil unit ratings remain unchanged for Arenosols (Q), Albic Arenosols (Qa), Cambic Arenosols (Qc), Ferralic Arenosols (Qf), Calcaro-cambic Arenosols (Qkc), Luvic Arenosols (Ql) and Vitric Andosols (Tv), since coarse texture limitations have been already applied in the soil unit ratings.

Soil unit ratings remain unchanged where textures are medium and fine: fine sandy loam (FSL), sandy loam (SL), loam (L), sandy clay loam (SCL), silt loam (SL), clay loam (CL), silty clay loam (SICL) and silt (SI); or fine: sandy clay (SC), silty clay (SIC), peaty clay (PC) and clay (C).

In all other cases, i.e. soil units with coarse textures – i.e. sand (S), loamy coarse sand (LCS), fine sand (FS), loamy fine sand (LFS), and loamy sand (LS) – the soil unit rating is lower by 25 percent for all crops.

4.4.3 Slope limitations

Slope limitations for all crops are presented in Table 4.12. The production system is the main factor influencing landform suitability assessment. In fact it is possible to utilise land with steeper slopes under CA than under TA. The slope rating of S1 means that the soil unit ratings, described in Section 4.3.2, remain unchanged. All ratings of soils with S2 slope rating are decreased or downgraded by one class, i.e. S1 soil rating changes to S2 if the slope rating is S2; S2 soil rating changes to N if the slope rating is S2; and all soil ratings of soils with N slope rating are downgraded to N.

TABLE 4.12

Slope rating by production system

Percent slope Production System	0 - 2	2 - 5	5 - 8	8 - 12	12 - 16	16 - 23	23 - 30	30 -45	45 - 60	> 60
TA	S1	S1	S2	S2	N	N	N	N	N	N
CA	S1	S1	S1	S1	S1	S2	S2	S2	S2	N

4.5 LAND SUITABILITY ASSESSMENT

When the land suitability assessment (Part I) of the productivity model is applied to the land resources inventory, the assessment of potential crop performance and consequently crop options to be selected for further processing in Part II of the model (Figure 2.1), by agro-ecological cell, may be undertaken. Subsequently, land that is reserved for other uses, such as cash-crop zones, irrigation schemes, forest zones, or reservation and conservation areas, is taken into account as appropriate (Chapter 5).

All three assessments: climatic suitability, edaphic suitability and soil/slope erosion hazard, are required to determine the ecological land suitability for crop production of each climate-soil unit of the land resources inventory. In essence the land suitability assessment takes account of all the inventoried attributes of land and compares them with the requirements of the crops, so that a simple and understandable picture of the suitability of land for crop production emerges.

The results of the land suitability assessment are presented in terms of six basic suitability classes, each linked to attainable yields for the three levels of inputs considered. For each level of input, the land suitability classes are: very suitable (VS) – 80 percent or more of the maximum attainable yield; suitable (S) – 60 to less than 80 percent of the maximum attainable yield; moderately suitable (MS) – 40 to less than 60 percent of the maximum attainable yields; marginally suitable (mS) – 20 to less than 40 percent; very marginally suitable (vmS) – one to less than 20 percent and not suitable (NS) – 0 percent.

In the first step, the crop temperature requirements with regard to photosynthesis and phenology are compared with the prevailing temperature conditions of each thermal zone. If they do not match, all the growing period zones in that thermal zone are classified as not suitable. If the temperature conditions of a thermal zone partially or fully match the crop thermal requirements, all growing period zones in that thermal zone are considered for further suitability assessment according to the thermal zone rating. This further assessment comprises application of length of growing period suitability to the computed areas of the various growing period zones by LGP-Pattern zone. Thus if the thermal zone rating of a particular growing period zone is S1, then potential yield biomass value for the growing period zone is not modified. If the thermal zone rating of the growing period zone is S3, then the potential yield biomass value for the computed extents of the period zone is decreased by 50 percent. The thermal and moisture suitability assessments are described in Sections 4.3.3 and 4.3.4.

The length of growing period suitability is applied according to the LGP-Pattern make-up. All annual crops are matched to the individual component length of growing period, i.e. LGP1 and LGP2. The LGP-Pattern evaluation for each crop is achieved by taking into account the constituent component lengths of each LGP. Also where the LGP is intermediate, then an appropriate reduction is applied for TA and for CA.

The next step is an appraisal of the soil units present in each growing-period zone. The rating of soil units for the crops and level of inputs under consideration are applied to the computed area of the growing period zone occupied by each soil unit. The appraisal, undertaken on the basis of the soil ratings as described in Section 4.4.1, leads to appropriate modifications of the climatic suitability assessment and the attainable yield. Subsequently, the ratings for the different soil textures are applied.

Finally, limitations imposed by slope are taken into account to arrive at the final land suitability appraisal for the crops, for the level of inputs under consideration.

The six classes of land suitability are related to attainable yields as percentages of the maximum attainable under the optimal climatic, edaphic and landform conditions for each LUT or for each crop under TA and under CA. Consequently the results provide, for each land unit, an assessment of crop production potentials, which can be aggregated for any given area.

The crop and land suitability assessment was performed using the Land Suitability Assessment software developed mainly under the BEFS project for country-specific analysis. Subsequent software improvements were required in order to perform the analysis at regional level. Technical details on the software may be found in Annex 4.

CHAPTER 5

Crop and land suitability assessments within a socio-economic context

In this chapter socio-economic information is presented in the form of possible layers that might be superimposed over crop and land suitability assessments in order to better target the results in terms of specific policy issues.

In the context of bioenergy sector development, two main issues have frequently been raised worldwide over the past few years:

- What is the potential trade-off that will occur in terms of land for food and energy crop production, with consequently potential negative impacts on food security?
- What are the opportunities and challenges that the bioenergy sector could generate in terms of employment, energy independence and rural development?

With these questions in mind, the assessment of land availability and the identification of areas where competition is very high were carried out. Furthermore, so as to link the analysis to real country situations, a set of socio-economic data were collected and geo-referenced.

5.1 ASSESSING THE AVAILABILITY OF LAND

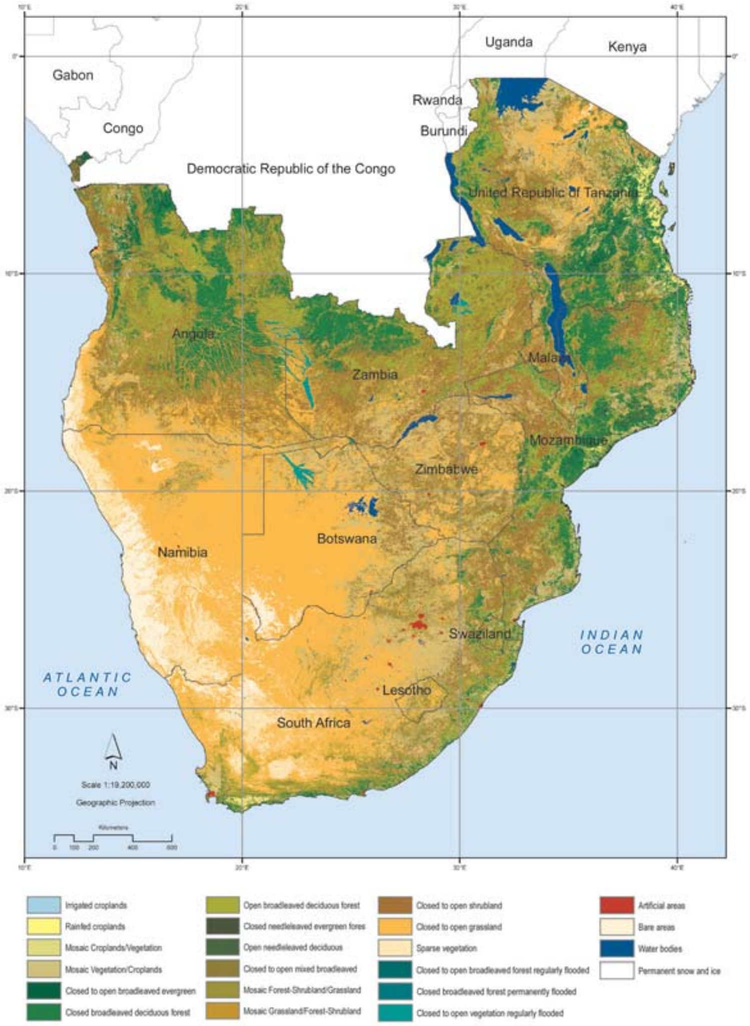
In order to use the land assessment as the instrument to provide information for agricultural planning and development, an accurate evaluation of land use/cover environmental constraints and potential legal restrictions is necessary. The assessment in this report was carried out under rainfed conditions; information on areas equipped for irrigation should be taken into account as appropriate. This chapter presents the main information and the land available for the Southern Africa region.

5.1.1 Land cover

First of all, information about the *status quo* of the land can help to identify areas where crops cannot be produced because of the existing environment (see Figure 5.1).

The European Space Agency (ESA) has created highly detailed portraits of the Earth's land surface. They are the first ones to have been produced as part of the ESA-initiated GlobCover project, carried out under ESA's Earth Observation Data User Element (DUE). An international network of partners is working with ESA on the

FIGURE 5.1
Land cover



project, including the United Nations Environment Programme (UNEP), FAO, the European Commission's Joint Research Centre (JRC), the European Environmental Agency (EEA), the International Geosphere-Biosphere Programme (IGBP) and the Global Observations of Forest Cover and Global Observations of Land Dynamics (GOFC-GOLD) Implementation Team Project Office.

The products are based on Envisat's Medium Resolution Imaging Spectrometer (MERIS) instrument working in full resolution mode to acquire images in polar orbit at an altitude of 800 km with a spatial resolution of 300 m. They refer to bimonthly global composites for May to June 2005 and March to April 2006.

The global land cover map was derived through an automatic and regionally adjusted classification of the MERIS global composites. The 22 land-cover classes are defined according to the UN Land Cover Classification System (LCCS), a comprehensive, standardized *a priori* classification system. The main objective of the initiative for definition of a reference classification was to respond to the need for standardization and to develop a common integrated approach to all aspects of land cover. This implies a methodology that is applicable at any scale, and which is comprehensive in the sense that any land cover identified anywhere in the world can be readily accommodated (FAO, 2000).

5.1.2 Protected areas

The World Database on Protected Areas (WDPA) was used to identify protected areas. A protected area is defined as a "*clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" (Dudley, 2008).

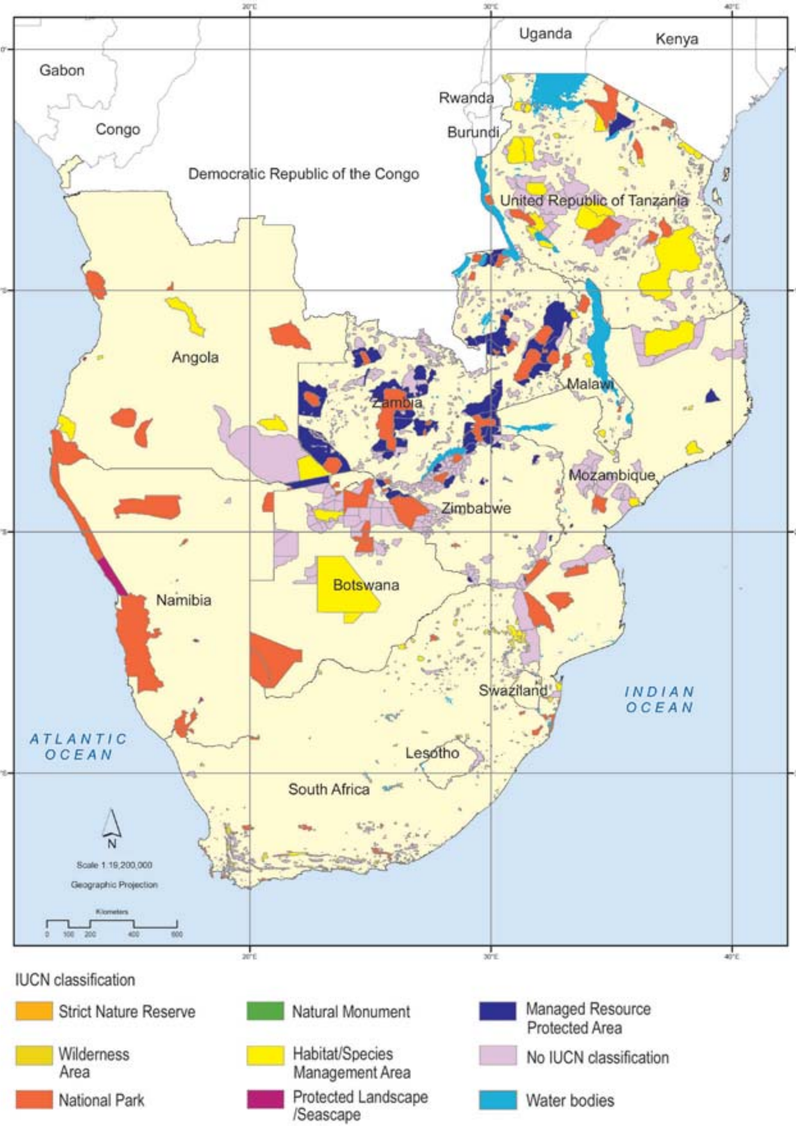
The International Union for Conservation of Nature (IUCN) has developed seven Protected Area Management Categories that define protected areas according to their management objectives and are internationally recognised by various national governments and the United Nations. The categories provide international standards for comparing the protected areas in different countries and encourage the planning of protected areas under management aims. The categories are: Ia, Strict Nature Reserve; Ib, Wilderness Area; II, National Park; III, Natural Monument of Feature; IV, Habitat/Species Management Area; V, Protected Landscape/Seascape and; VI, Protected area with sustainable use of natural resources. Figure 5.2 shows the geographic distribution of protected areas in the study region by management categories in the year 2005.

In Southern Africa region, protected areas represent almost 20 percent of the overall territory; they are fairly homogeneously distributed. Zambia, Botswana and Tanzania have the largest extent of protected areas, ranging from 30–36 percent, as shown in Table 5.1.

TABLE 5.1
Extent of protected areas by country as percentage of total land area

Country	Protected areas	Total Land
	%	'000 ha
Angola	12.1	124,945
Botswana	30.5	57,178
Lesotho	0.7	2,968
Malawi	16.0	9,483
Mozambique	16.1	77,636
Namibia	13.4	82,083
South Africa	6.9	120,067
Swaziland	2.8	1,637
Tanzania	28.5	88,107
Zambia	35.9	73,638
Zimbabwe	27.7	38,318
Total	**19.0**	**676,060**

FIGURE 5.2
Protected areas



5.1.3 Irrigation areas

From the previous chapters, it has been seen that the crop and land suitability assessment in this study was carried out assuming rainfed production. It should be kept in mind that areas under irrigation are not affected by limited precipitation, and could thus produce higher crop yields than in rainfed areas as long as care is taken that water is always available in the most crucial phase of crop production. The information on irrigated areas was produced globally by FAO combining sub-national irrigation statistics from national census surveys and reports with geospatial information on the position and extent of irrigation schemes (Siebert *et al*., 2007). For most of the countries, these statistics refer to the area equipped for irrigation. For a variety of reasons, the area actually irrigated may be significantly lower than the area equipped for irrigation. However, some countries report only the area that is actually irrigated in the year of the census (cf. Australia and India).

In order to gather information on how irrigated area is distributed within the sub-national units, geospatial information on position and extent of irrigated areas was derived by digitising hundreds of irrigation maps available in reports from irrigation associations, national ministries of agriculture, FAO or the World Bank. Additionally, information from several atlases or inventories, based on remote sensing available in digital format, was utilised. For most of the countries, more than one data source was used.

Figure 5.3 shows the distribution of the amount of area equipped for irrigation in percentage of the total area of the pixel.

The extent of irrigation area by country is reported in Table 5.2. Swaziland and South Africa have the largest extent of irrigation infrastructure; in Malawi, even if irrigated area covers only 0.4 percent of the total land, it is widely distributed throughout the country. Overall, in Southern Africa region, irrigated areas represent only 0.2 percent of total land area.

TABLE 5.2

Extent of irrigation area by country as percentage of total land area

Country	Irrigation areas	Total Land
	%	'000 ha
Angola	0.045	124,945
Botswana	0.002	57,178
Lesotho	0.056	2,968
Malawi	0.414	9,483
Mozambique	0.106	77,636
Namibia	0.007	82,083
South Africa	0.864	120,067
Swaziland	2.104	1,637
Tanzania	0.146	88,107
Zambia	0.147	73,638
Zimbabwe	0.315	38,318
Total	**0.239**	**676,060**

FIGURE 5.3
Irrigation areas

5.1.4 Land availability and conflicting usages

The information presented above was selected as appropriate from global information in order to produce two new maps. First the exclusion areas were identified selecting the following items from the different databases:

- Closed forests, extracted from the GlobCover database;
- Protected areas, extracted from the WDPA database;
- Artificial and bare areas, permanent snow and ice, extracted from the GlobCover database;
- Irrigation areas, extracted from the homonymous FAO database.

FIGURE 5.4
Excluded areas

Figure 5.4 shows the geographical location and extent of the excluded areas, the largest of which are protected areas. The yellow area is the land available for bioenergy crop production.

Closed forests and protected areas were excluded as potential areas for bioenergy crop production for their valuable interest in terms of environment and ecosystem.

Artificial areas were excluded for conflicting usage: in most cases the actual urbanized areas are very productive land where in the past farmers used to concentrate for the cultivation of cash crops to resell quickly in the market.

In most recent period the agricultural markets stimulated the development of other sectors and the consequent urbanization of productive areas was the main result of the modern conversion.

Bare land, permanent snow and ice, even if very limited in the extent, were excluded for the constraints they represent for agricultural production.

Finally the irrigation areas were excluded only because the analysis is carried out under the assumption of rainfed agriculture.

Once the areas listed as “excluded” were subtracted from total land under consideration, then the rest of the land could be assessed for suitability for bioenergy crop. Different methods for attaining maximum yield might occur in areas where agriculture is already being practiced, or areas not designed for bioenergy crop production.

A further screening of these areas would be required, guided mainly by policy objectives set by each country. Some countries may be interested in maintaining areas already under cultivation for food in order to ensure food security. In this particular context policymakers might be interested to learn more about opportunities for agricultural expansion and reclassify currently utilised agricultural land as an area with conflicting usage. Bioenergy crop cultivation expansion could then move onto land classified as shrub or grassland. Countries with very limited available land might decide to develop the bioenergy sector through an intensification of the actual land dedicated to crop production.

Figure 5.5 depicts the areas for agricultural expansion and intensification regardless of the degree of suitability for a specific land utilization type (LUT). The information on total land and total available land for expansion or intensification is summarised in Table 5.3.

TABLE 5.3

Total land and total available land by country

Country	**Total land**	**Land excluding conflicting usages**	**Land for agriculture expansion**	**Land for agriculture intensification**
	‘000 ha	**‘000 ha**	**‘000 ha**	**‘000 ha**
Angola	124,945	88,407	79,333	9,074
Botswana	57,178	45,949	36,581	9,368
Lesotho	2,968	2,950	2,300	650
Malawi	9,483	7,359	5,217	2,142
Mozambique	77,636	50,223	37,814	12,409
Namibia	82,083	65,121	61,560	3,561
South Africa	120,067	105,405	83,549	21,856
Swaziland	1,637	1,250	939	311
Tanzania	88,107	56,876	38,264	18,612
Zambia	73,638	45,745	40,313	5,432
Zimbabwe	38,318	32,487	21,787	10,700
Total	**676,060**	**501,773**	**407,657**	**94,116**

FIGURE 5.5
Agricultural expansion and intensification areas

5.2 SOCIO-ECONOMIC CONTEXT

Data on infrastructure, population and malnutrition could help to design more solid policy recommendations on crop promotion and land use planning with an orientation towards rural development and poverty reduction.

5.2.1 Infrastructure

Lack of infrastructure is one of the main limiting factors for the expansion of industry. Most of agricultural areas in Africa continue to be hampered by lack of access to competitive markets as a result of high transport and transaction costs.

The source of the infrastructure database is Vector Map (VMap) Level 0. This is an updated and improved version of the National Imagery and Mapping

Agency's (NIMA) Digital Chart of the World (DCW). The VMap Level 0 database provides worldwide coverage of vector-based geospatial data that can be viewed at 1:1,000,000 scale.

Figure 5.6 shows differences in the infrastructure distribution *amongst* and *within* countries.

FIGURE 5.6

Infrastructure

5.2.2 Population

The crop and land suitability assessment described in this report is a method for evaluating productivity potential of the land area for rainfed agriculture.

This information in itself is not sufficient for supporting policymakers in designing solid land use planning (i.e. food vs. fuel, internal consumption vs. export). Any potential productivity should be evaluated first of all in comparison to the number of people living in the specific area, and how much food and energy they will require. The expansion of a new sector such as biofuels will require people: farmers living in rural areas to produce bioenergy crop; skilled and unskilled workers to convert crops into bioenergy.

Combining the information on population with potential productivity data, will make it possible for agricultural economists and rural planners to characterise populations in relation to physical and environmental factors that affect their livelihood options and vulnerability to poverty and food insecurity, and finally assess the effects that producing biofuels could have in a specific area.

Figure 5.7 illustrates the urban and rural population distribution in the study region. The information is extracted from the Poverty Mapping Urban and Rural (PMUR) population database data generated by the LandScan Global Population Database and Nighttime Lights of the World (FAO, 2005).

From an agro-climatic perspective in Southern Africa region, the population is concentrated in the moist semi-arid and sub-humid zone with temperatures higher than 20 °C. The information reported in Table 5.4 also shows that almost 3.8 million people (2.3 percent) in the region lives in arid zones, the most severe environment for crop production.

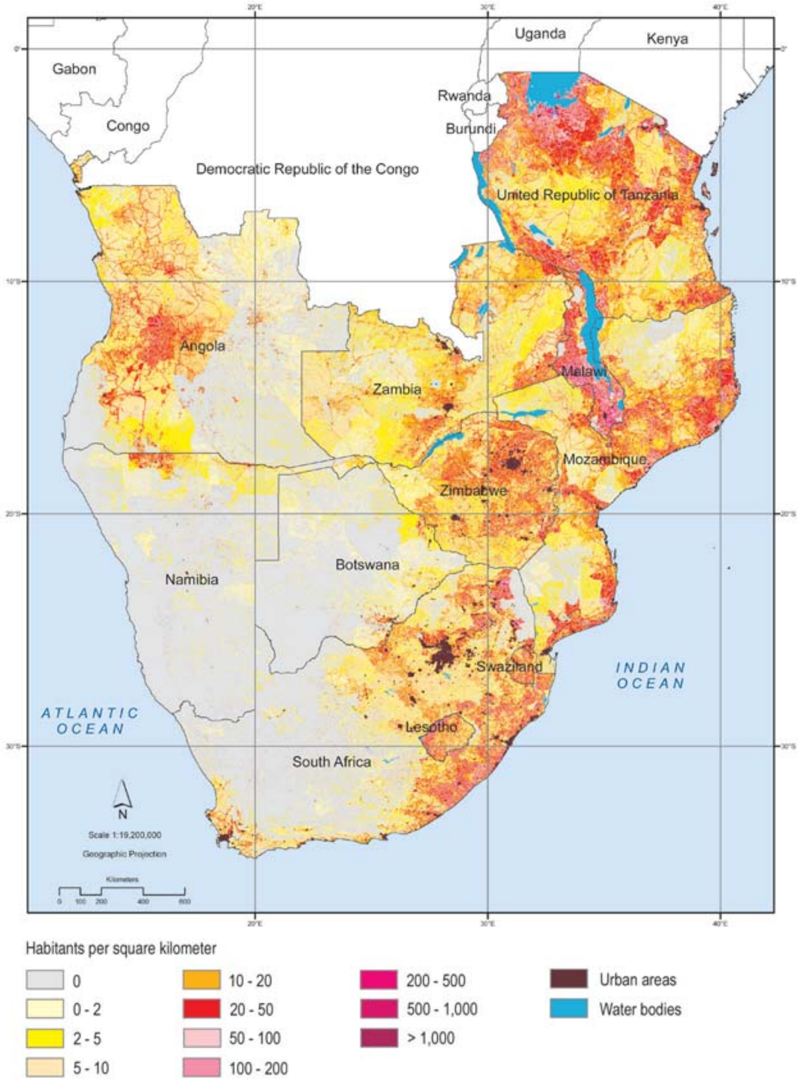
TABLE 5.4

Population distribution by agro-climatic condition

		Temperature		**Population by LGP zones ('000)**	**Population density (hab/sqkm)**	**Population by LGP zones (% on total)**
		T < 20°C	**T > 20°C**			
LGP zones	Arid 0<LGP<60	0.8	1.4	**3,746**	26	*2.3*
	Semi-arid 60<LGP<119	1.5	7.5	**14,875**	133	*9.0*
	Moist semi-arid 120<LGP<179	7.7	47.9	**91,871**	348	*55.6*
	Sub-humid 180<LGP<269	10	18.5	**47,178**	308	*28.6*
	Humid LGP>270days	4.3	0.2	**7,482**	2,268	*4.5*
Population by temperature ('000)		**40,332**	**124,819**	**165,151**	**244**	
Population by temperature (% on total)		*24.4*	*75.6*			

FIGURE 5.7

Urban and rural population density



5.2.3 Poverty and malnutrition

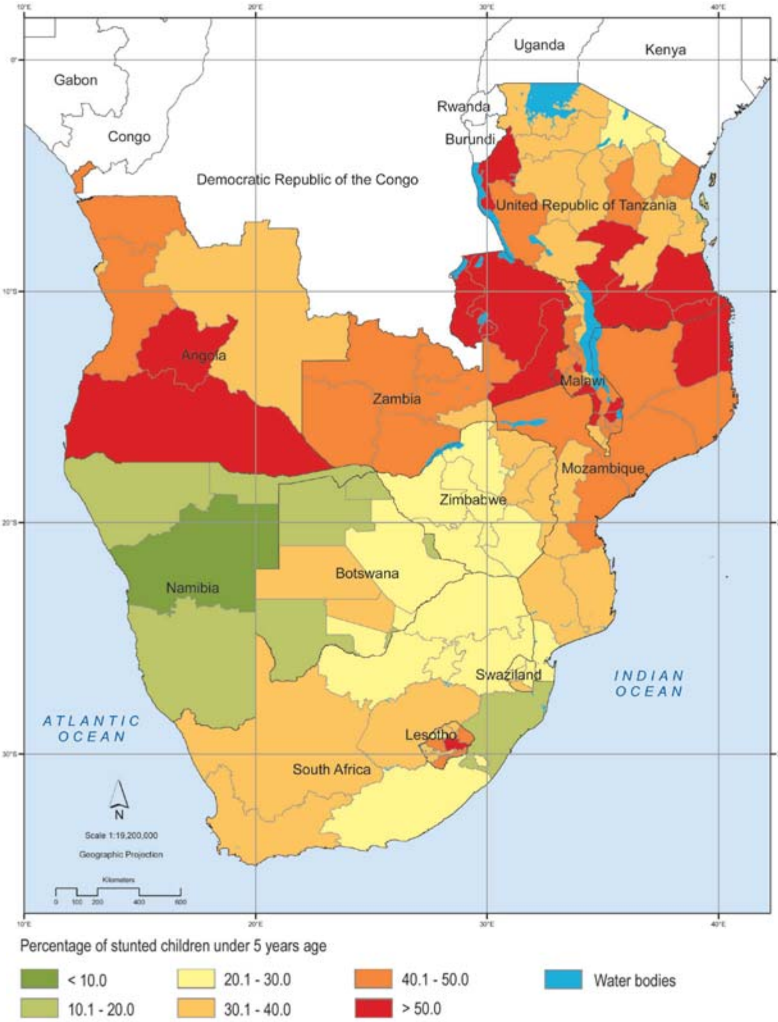
Stunting is reduced growth rate in human development, usually as a result of malnutrition in early childhood. The resulting diminutive stature (up to 20 cm shorter than expected in moderate stunting of a five-year old child) results in diminished cognition, disease resistance and labour capacity for the individual. This in turn has a significant effect on household and community productivity, which will further exacerbate regional food security problems in the future. A stunting indicator thus reflects long-term cumulative effects of inadequate food intake and poor health conditions as a result of lack of hygiene and recurrent illness in poor and unhealthy environments. The prevalence of chronic undernutrition is a relevant and valid measure of endemic poverty, and is a better indicator than estimates of per capita income.

The main sources of nutritional information are: Demographic and Health Surveys (under the project MEASURE DHS), UNICEF (through the international household survey initiative called the Multiple Indicator Cluster Surveys) and World Health Organization (Global Database on Child Growth and Malnutrition). The surveys in the countries were carried out in the decade 2000–2010.

As shown in Figurer 5.8, the major food insecurity “hotspot” areas are to be found in the southern parts of Tanzania and Angola and the eastern part of Zambia.

FIGURE 5.8

Chronic undernutrition among children



CHAPTER 6

Application: Land available for bioenergy crops

The results of the crop and land suitability assessment are presented in this chapter. The results are divided by crop with results presented in map and table format with a discussion for each crop and type. It should be noted that crops for ethanol (cassava, sugarcane and sweet sorghum) were grouped together and examined before the crops used for biodiesel production (oil palm and sunflower). The following points are covered in the discussion for each crop:

- Crop agro-climatic suitability, presented in map format for each Land Utilization Type (LUT) and in tabular format showing agro-climatic suitable area data as the percentage of total land by country and LUT;
- Land suitability in tabular format, presented as the percentage of suitable area on total land area by country and LUT;
- Suitability index in map format;
- Available suitable land in map format showing the geographic location of potential land for the expansion of crop production by suitability classes, and in tabular format presenting the percentage of suitable land and potential production in the suitable area in case of crop intensification and expansion.

All maps and tables are presented so that the reader can easily perceive (a) the differences between production systems and input levels; (b) the geographical distribution of crop and land suitability; and (c) the suitability index and available suitable land area for expansion and intensification.

In the context of this study, suitable land area is the area classified as moderately suitable, suitable and very suitable. This corresponds to the area where more than 40 percent of the maximum agronomically attainable yield can be achieved.

The tables show data for the eleven countries in Southern Africa region, namely Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, the United Republic of Tanzania, Zambia and Zimbabwe.

The land area is considered as potentially available for crop production once all the land areas with environmental purposes and other usages are subtracted from the evaluation due to non-availability as described in detail in Section 5.1.4.

Furthermore, particular attention was given to land area already under agricultural use. As described in Section 5.1.4, agricultural land area is treated in two ways. In the first instance, it is foreseen as an area to be reserved for maintaining food production and future expansion of agricultural land is considered. This could be a decision made in large-sized countries with food insecurity issues that must be resolved, or which have high-technology potential accompanied by a large demand for alternative energy. In the second instance production intensification on current agricultural land could be the only solution for the development of the biofuel sector. It is the case of small-size countries with relatively low crop yields and food insecurity concerns. If managed sustainably and properly, such development could generate opportunities for the improvement of the agricultural sector and consequently help to alleviate food insecurity concerns. The CD enclosed contains the full results of the assessment. A description of the CD is in Annex 5.

6.1 CROPS FOR ETHANOL PRODUCTION

The first three crops presented here can be considered for ethanol production, namely cassava, sugarcane and sweet sorghum (lowland and highland). In this report the feasibility of bioenergy crops has been studied only in terms of the biophysical or the agro-ecological potential production of the crop. In order to provide support and information for policy-making decisions, further analysis is required in order to assess the feasibility and the competitiveness of the transformation of feedstocks into biofuel, based on the technical capacities of each of the specific country.

6.1.1 Cassava

The geographical distribution of the agro-climatic suitability of cassava at low- and high-input level is shown for tillage-based agriculture (TA) in Figure 6.1, and for Conservation Agriculture (CA) in Figure 6.2. Under TA, 11.13 percent of the total regional land area (676 million ha) is agro-climatically suitable for cassava production, whereas under CA, 24.26 percent of the total regional land area is suitable (Table 6.1). Four countries, Mozambique, Tanzania, Malawi, and Angola, account for the bulk of the agro-climatically suitable land area in the region for cassava.

When soil and terrain (slope) constraints are applied to the agro-climatic suitability assessment, regional land suitability for cassava drops to 4.38 percent under low inputs and 5.37 percent under high inputs for TA (Table 6.2). For CA, regional land suitability drops to 10.87 percent under low inputs and to 11.64 percent under high inputs. Thus over 50 percent of the agro-climatic potential is downgraded due to soil and terrain constraints. However, there is more than double the amount of suitable land area under CA compared with what is available under TA.

FIGURE 6.1

Agro-climatic suitability for cassava under tillage-based production at high and low level of inputs

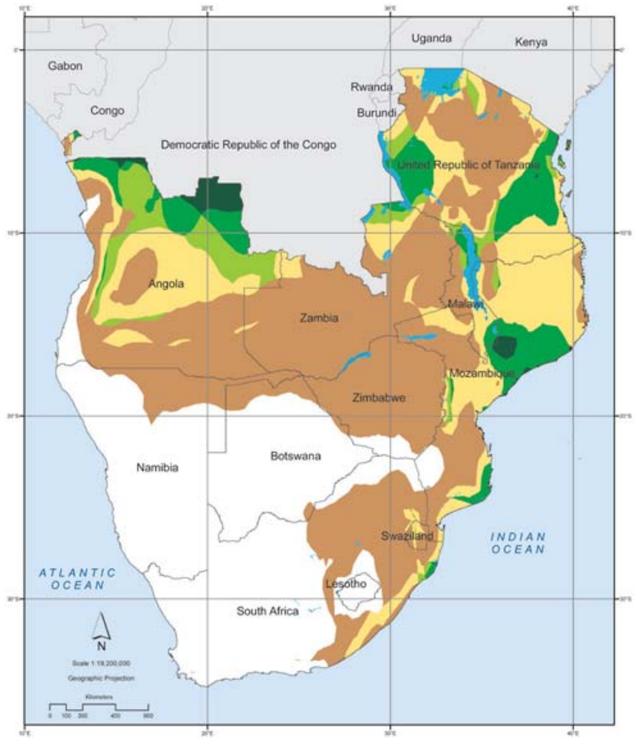
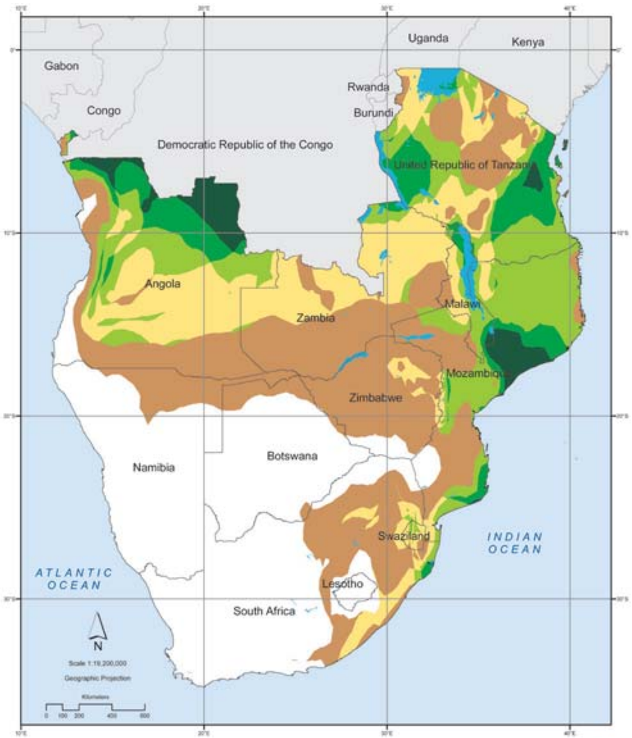


FIGURE 6.2

Agro-climatic suitability for cassava under Conservation Agriculture at high and low level of inputs



■ Very Suitable (80-100%)
🟩 Suitable (60-80%)
🟩 Moderately Suitable (40-60%)
🟨 Marginally Suitable (20-40%)
🟫 Very Marginally Suitable (< 20%)
□ Not Suitable
🟦 Water bodies

TABLE 6.1

Percentage of agro-climatic suitable[1] land for cassava

Country	Tillage-based production	Conservation Agriculture	Total Land Area
	With low and high input	With low and high input	'000 ha
Angola	34.66	44.40	124,945
Botswana	-	-	57,178
Lesotho	-	-	2,968
Malawi	21.41	55.20	9,483
Mozambique	17.42	64.97	77,636
Namibia	-	-	82,083
South Africa	0.53	1.05	120,067
Swaziland	9.26	19.32	1,637
Tanzania	22.59	54.00	88,107
Zambia	2.99	5.05	73,638
Zimbabwe	0.01	0.03	38,318
Total	**11.13**	**24.26**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.2

Percentage of suitable[1] land for cassava

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	9.69	24.95	13.07	24.99	124,945
Botswana	-	-	-	-	57,178
Lesotho	-	-	-	-	2,968
Malawi	20.03	51.71	20.06	51.77	9,483
Mozambique	8.34	23.86	8.83	25.15	77,636
Namibia	-	-	-	-	82,083
South Africa	0.29	0.50	0.37	0.52	120,067
Swaziland	1.00	9.23	2.83	9.26	1,637
Tanzania	7.90	16.70	10.10	21.40	88,107
Zambia	2.51	4.66	2.51	4.66	73,638
Zimbabwe	-	-	-	-	38,318
Total	**4.38**	**10.87**	**5.37**	**11.64**	**676,060**

[1] includes moderately to very suitable land

Regional distribution of the Land Suitability Index for cassava at low-input levels is shown in Figures 6.3 and 6.4 for TA and CA, respectively, and at high-input levels in Figures 6.5 and 6.6. These thematic maps show, within the zones of agro-climatic suitability, the location of the suitable land for cassava within each country of the region.

Estimates of suitable land available for cassava expansion and its potential production are presented in Tables 6.3 and 6.5 and for cassava intensification in Tables 6.4 and 6.6. Figures 6.7 and 6.8 show the distribution of potentially suitable land area for expansion with high-input levels under TA and CA, respectively. At low-input levels, there are almost 100,000 ha of suitable land for expansion under TA (corresponding to 29.6 million tonnes fresh weight) and around 315,000 ha under CA (corresponding to 81.2 million tonnes). Suitable land for expansion at high-input levels increases to 500 202 ha (more than five-fold difference) under TA (corresponding to 140 million tonnes) and around 1.2 million ha under CA (some four-fold difference) (corresponding to 337.6 million tonnes). Given the possibility of greater potential land availability and yield for cassava under CA, area expansion of cassava to meet biofuel demand would have a relatively lower effect on cassava-based food security component than under TA.

Given the information on cassava adaptability to climate and soil, the procedure for estimating land suitability for expansion and intensification, it becomes possible to consider and decide where and with what production system a certain development target for biofuel could be met sustainably and with minimum negative impact on food security. This forms a basis for scenario-type estimates that can be generated through the methodology laid out in this report. While constructing the scenario, the possibility of alternative bioenergy crops, along with possible effects on the component (commodity-specific) and overall food security of any planning decision to expand and intensify production of a particular bioenergy crop or a set of bioenergy crops can consequently be taken into account.

FIGURE 6.3
Land suitability index for cassava under tillage-based production at low level of inputs

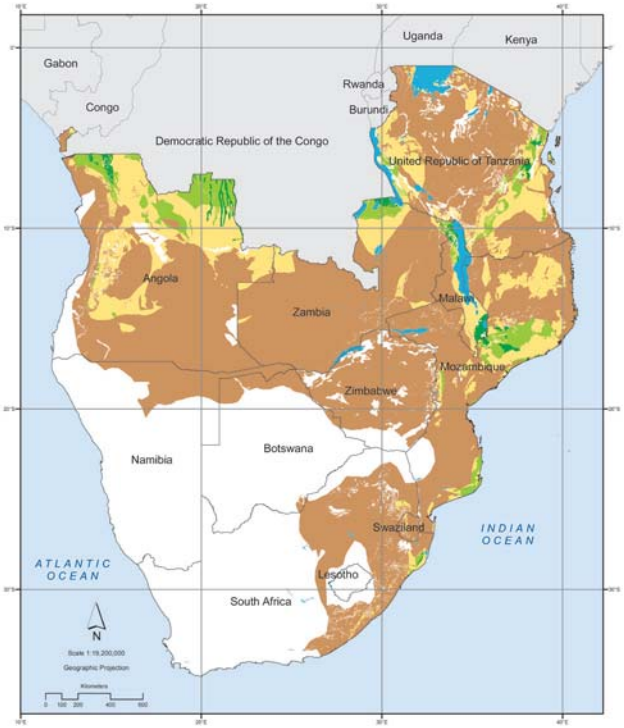
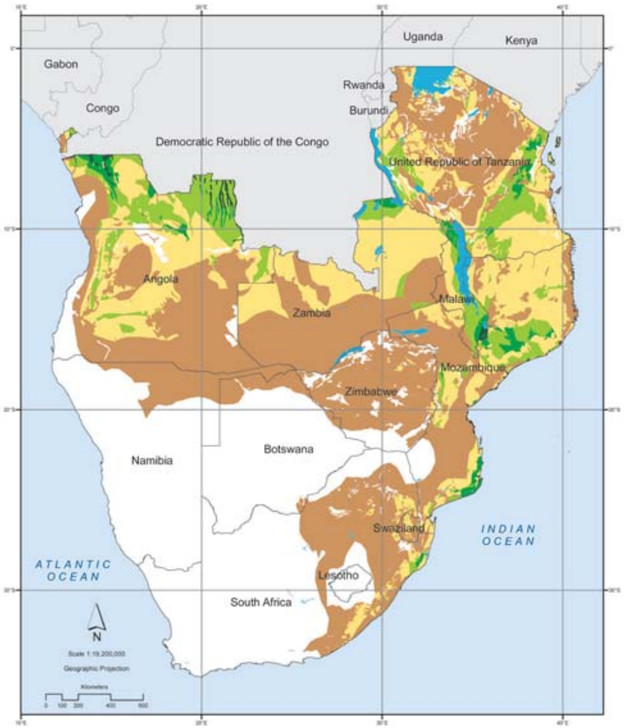


FIGURE 6.4
Land suitability index for cassava under Conservation Agriculture at low level of inputs



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- □ Not Suitable
- ■ Water bodies

FIGURE 6.5

Land suitability index for cassava under tillage-based production at high level of inputs

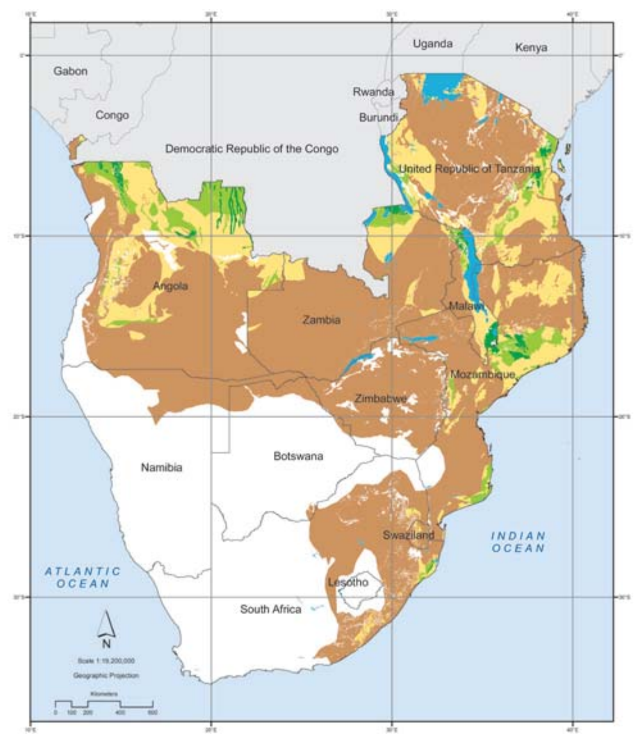
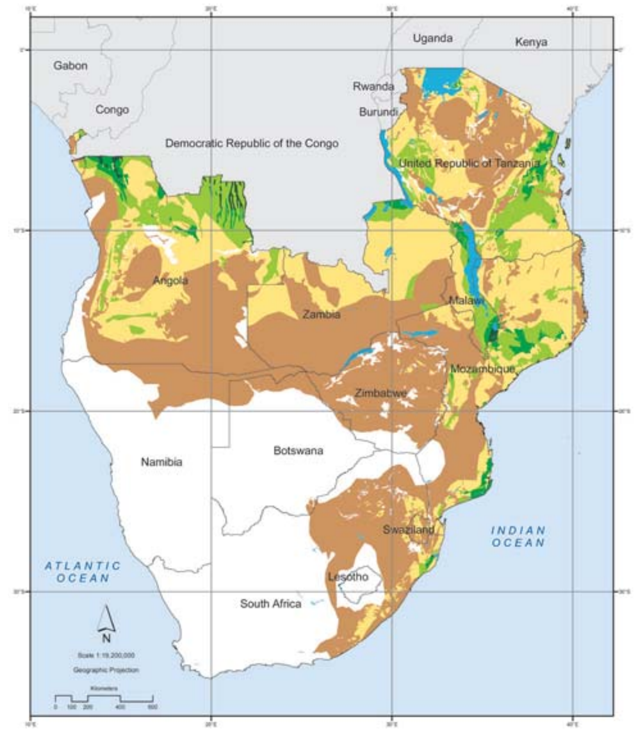


FIGURE 6.6

Land suitability index for cassava under Conservation Agriculture at high level of inputs



■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
□ Not Suitable
■ Water bodies

TABLE 6.3

Percentage of suitable[1] land for cassava expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	9.70	24.80	13.00	24.82	79,333
Botswana	-	-	-	-	36,581
Lesotho	-	-	-	-	2,300
Malawi	16.63	49.28	16.67	49.35	5,217
Mozambique	6.05	19.92	6.53	20.99	37,814
Namibia	-	-	-	-	61,560
South Africa	0.19	0.32	0.24	0.32	83,549
Swaziland	0.71	7.51	1.93	7.56	939
Tanzania	5.87	13.24	8.12	18.07	38,264
Zambia	2.01	3.98	2.01	3.98	40,313
Zimbabwe	-	-	-	-	21,787
Total	**3.45**	**9.02**	**4.36**	**9.58**	**407,657**

[1] includes moderately to very suitable land

TABLE 6.4

Percentage of suitable[1] land for cassava intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	9.24	19.75	11.52	19.86	9,074
Botswana	-	-	-	-	9,368
Lesotho	-	-	-	-	650
Malawi	22.45	50.62	22.47	50.66	2,142
Mozambique	13.03	26.87	13.58	28.93	12,409
Namibia	-	-	-	-	3,561
South Africa	0.45	0.67	0.53	0.69	21,856
Swaziland	1.70	16.64	6.24	16.68	311
Tanzania	5.25	12.82	7.21	17.83	18,612
Zambia	2.26	6.63	2.26	6.63	5,432
Zimbabwe	-	-	-	-	10,700
Total	**4.40**	**9.73**	**5.11**	**11.01**	**94,116**

[1] includes moderately to very suitable land

TABLE 6.5

Cassava production ('000 tons) in suitable[1] land available for expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	53,145	172,037	287,083	634,910
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	6,774	21,805	27,164	80,520
Mozambique	17,193	62,055	75,557	241,938
Namibia	-	-	-	-
South Africa	1,086	2,190	5,252	8,224
Swaziland	37	513	401	1,903
Tanzania	15,087	44,185	84,573	220,504
Zambia	5,042	12,745	20,171	46,996
Zimbabwe	-	2	2	6
Total	**98,365**	**315,533**	**500,202**	**1,235,001**

[1] includes moderately to very suitable land

TABLE 6.6

Cassava production ('000 tons) in suitable[1] land available for intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	6,093	16,371	30,151	60,658
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	3,648	9,542	14,599	35,199
Mozambique	11,367	29,729	48,801	117,492
Namibia	-	-	-	-
South Africa	640	1,220	3,045	4,654
Swaziland	30	383	440	1,418
Tanzania	7,100	21,168	39,958	107,960
Zambia	757	2,761	3,028	10,179
Zimbabwe	-	1	1	4
Total	**29,635**	**81,175**	**140,023**	**337,564**

[1] includes moderately to very suitable land

FIGURE 6.7

Potential land for cassava expansion under tillage-based production at high level of inputs by suitability index

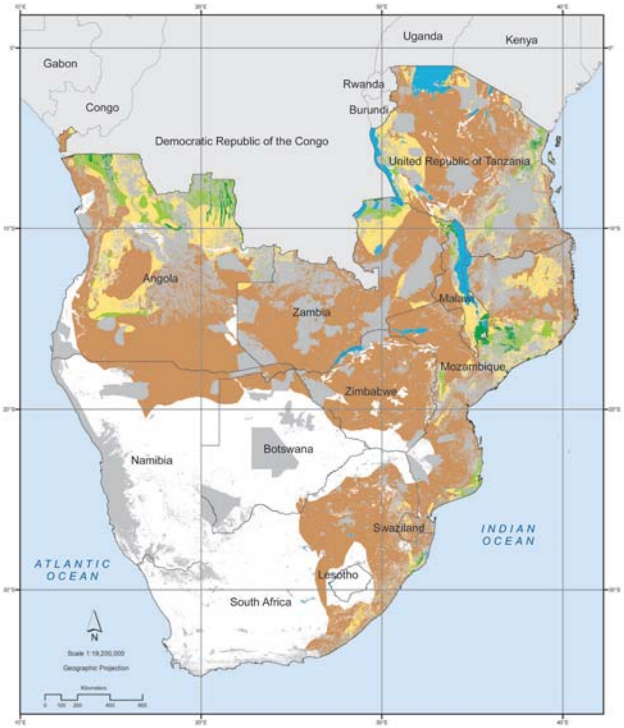
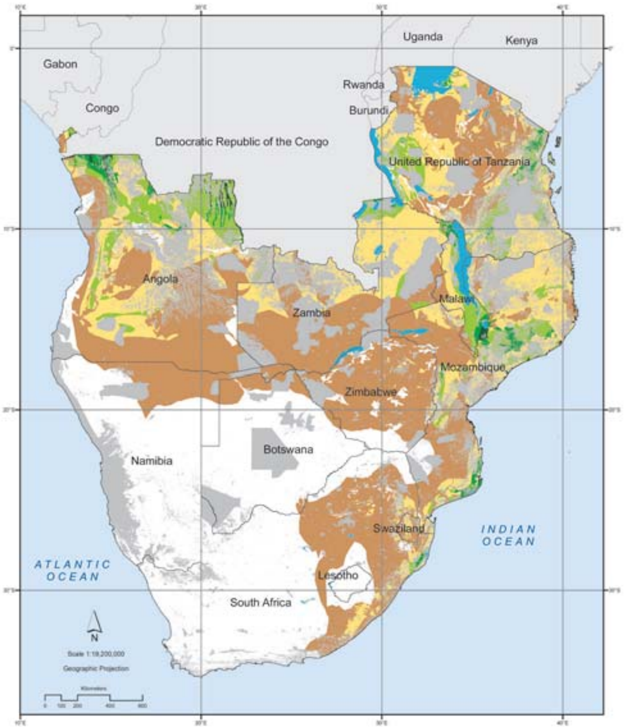


FIGURE 6.8

Potential land for cassava expansion under Conservation Agriculture at high level of inputs by suitability index



■	Very Suitable (80-100%)
■	Suitable (60-80%)
■	Moderately Suitable (40-60%)
■	Marginally Suitable (20-40%)
■	Very Marginally Suitable (< 20%)
□	Not Suitable
■	Excluded areas
■	Water bodies

6.1.2 Sugarcane

In the case of sugarcane, the geographical distribution of the agro-climatic suitability at low- and high-input level is shown for TA in Figure 6.9, and for CA in Figure 6.10. Under TA, 2.06 percent of the total regional land area (676 million ha) is agro-climatically suitable for sugarcane production, whereas under CA, 4.31 percent of the total regional land area is suitable (Table 6.7). Angola, Mozambique, Tanzania and – mainly under CA – Malawi account for the bulk of the agro-climatically suitable land area in the region for sugarcane.

Regional land suitability for sugarcane drops to the range 0.38–0.54 percent, respectively, under low and high inputs for TA (Table 6.8). For CA, regional land suitability drops to 1.53 percent under low inputs and to 1.66 percent under high inputs.

Thus over 60 percent of the agro-climatic potential must be downgraded because of soil and terrain constraints. However, the amount of suitable land area under CA is five times larger than that under TA.

Geographical distribution of the Land Suitability Index for sugarcane at low-input level is shown in Figures 6.11 and 6.12 for TA and CA, respectively, and at high-input level in Figures 6.13 and 6.14. The suitable area is concentrated mainly in northern Angola, the north coast of Tanzania and in the Zambezi River basin in Mozambique.

Estimates of suitable land available for sugarcane expansion and its potential production are presented in Tables 6.9 and 6.11 and for sugarcane intensification in Tables 6.10 and 6.12. Figures 6.15 and 6.16 show the distribution of potentially suitable land area for expansion with high-input levels under TA and CA, respectively. At low-input levels, there are slightly more than 1 million ha of suitable land under TA (corresponding to 6.5 million tonnes of sugar) and around 4.6 million ha under CA (corresponding to almost 33 million tonnes of sugar). Suitable land for expansion at high-input levels increases to 1.6 million ha under TA (corresponding to 9.5 million tonnes) and 4.7 million ha under CA (corresponding to 34 million tonnes of sugar).

The potential area for intensification is very limited in both agricultural production systems.

It is very important to remember that this analysis was carried out under rainfed condition. More suitable land is feasible under irrigation, as moisture is the major limiting factor with respect to this crop. An appropriate analysis of water availability for sugarcane production must be carried out beforehand in order to identify the locations where there is no evidence of competition for scarce water resources.

FIGURE 6.9

Agro-climatic suitability for sugarcane under tillage-based production at high and low level of inputs

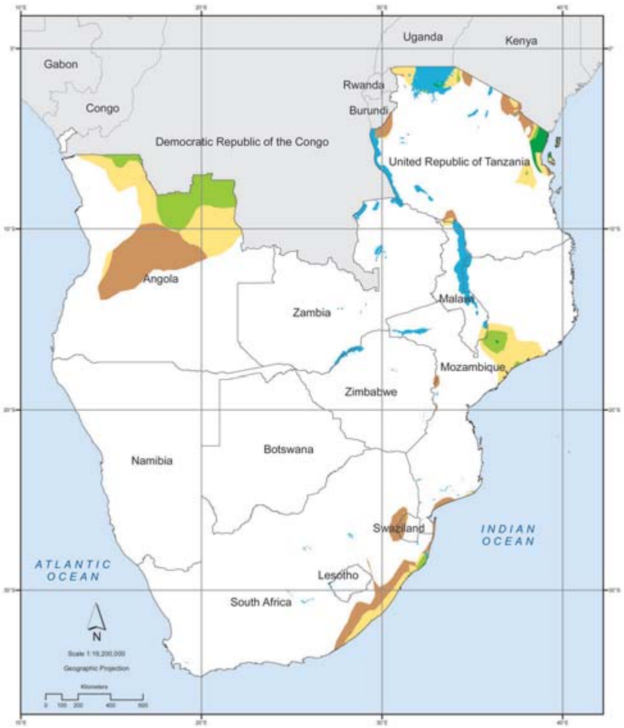
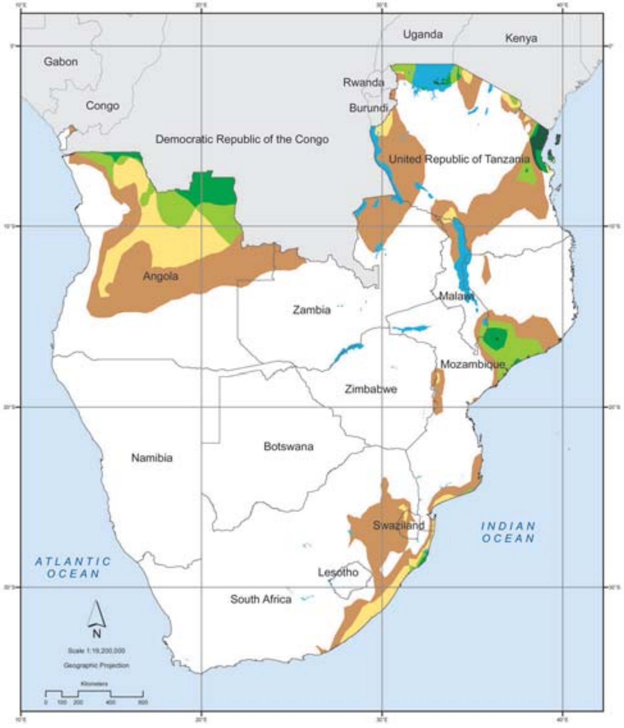


FIGURE 6.10

Agro-climatic suitability for sugarcane under Conservation Agriculture at high and low level of inputs



■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
☐ Not Suitable
■ Water bodies

TABLE 6.7

Percentage of agro-climatic suitable[1] land for sugarcane

Country	**Tillage-based production**	**Conservation Agriculture**	**Total Land Area**
	With low and high input	With low and high input	‘000 ha
Angola	8.20	13.11	124,945
Botswana	-	-	57,178
Lesotho	-	-	2,968
Malawi	0.58	3.54	9,483
Mozambique	2.05	8.63	77,636
Namibia	-	-	82,083
South Africa	0.23	0.30	120,067
Swaziland	-	-	1,637
Tanzania	1.97	6.10	88,107
Zambia	-	-	73,638
Zimbabwe	-	-	38,318
Total	**2.06**	**4.31**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.8

Percentage of suitable[1] land for sugarcane

Country	**Tillage-based production**	**Conservation Agriculture**	**Tillage-based production**	**Conservation Agriculture**	**Total Land Area**
	With low input		With high input		‘000 ha
Angola	0.75	4.25	1.36	4.40	124,945
Botswana	-	-	-	-	57,178
Lesotho	-	-	-	-	2,968
Malawi	0.41	2.97	0.41	2.97	9,483
Mozambique	0.93	2.27	0.99	2.27	77,636
Namibia	-	-	-	-	82,083
South Africa	0.06	0.13	0.07	0.13	120,067
Swaziland	-	-	-	-	1,637
Tanzania	0.88	3.22	1.19	3.97	88,107
Zambia	-	-	-	-	73,638
Zimbabwe	-	-	-	-	38,318
Total	**0.38**	**1.53**	**0.54**	**1.66**	**676,060**

[1] includes moderately to very suitable land

FIGURE 6.11
Land suitability index for sugarcane under tillage-based production at low level of inputs

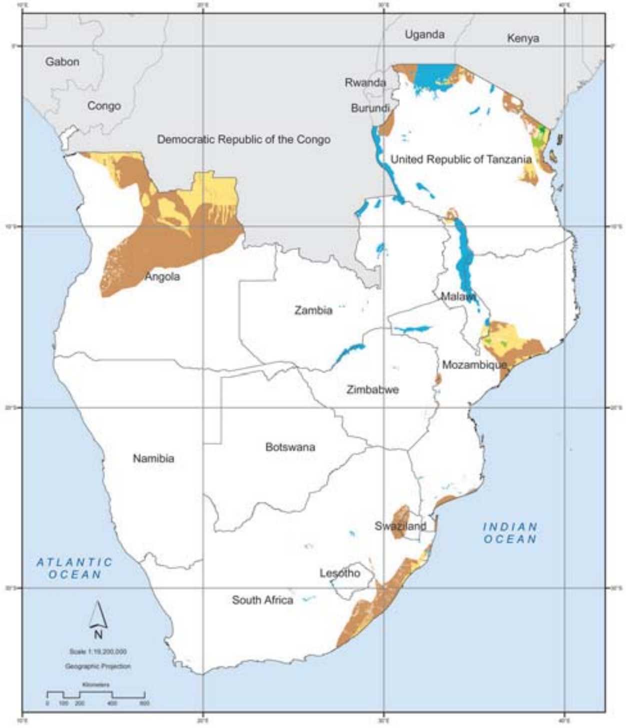
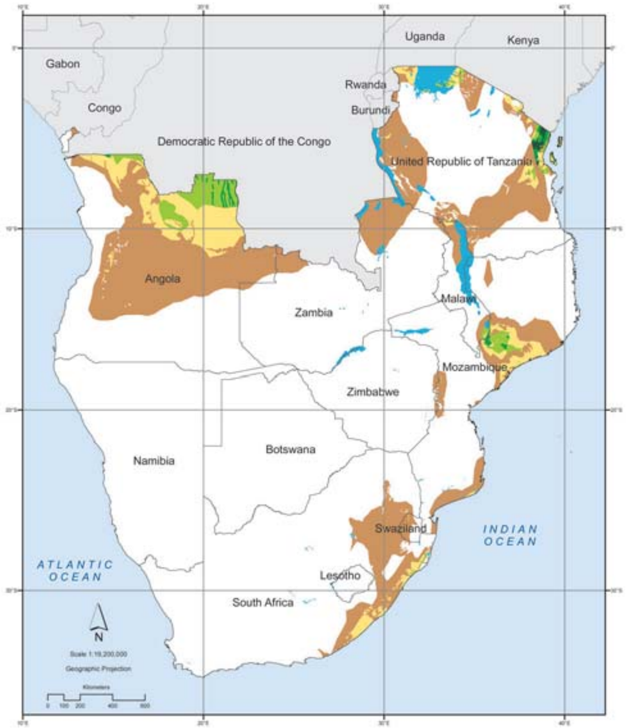


FIGURE 6.12
Land suitability index for sugarcane under Conservation Agriculture at low level of inputs



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- □ Not Suitable
- ■ Water bodies

FIGURE 6.13

Land suitability index for sugarcane under tillage-based production at high level of inputs

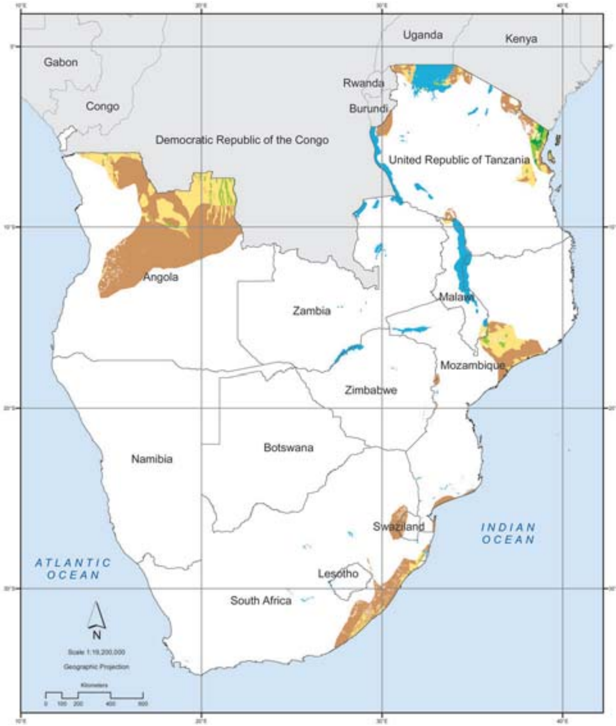
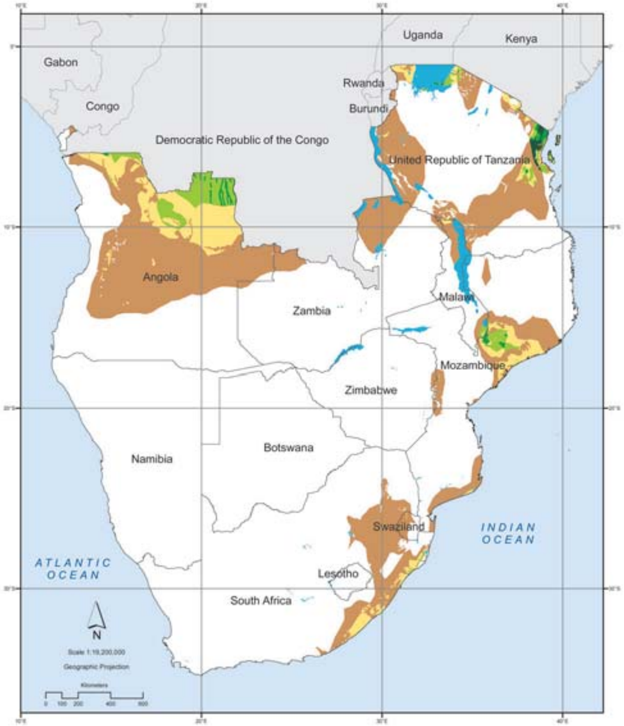


FIGURE 6.14

Land suitability index for sugarcane under Conservation Agriculture at high level of inputs



■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
□ Not Suitable
■ Water bodies

TABLE 6.9

Percentage of suitable[1] land for sugarcane expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		‘000 ha
Angola	0.80	3.96	1.35	4.07	79,333
Botswana	-	-	-	-	36,581
Lesotho	-	-	-	-	2,300
Malawi	0.26	3.40	0.26	3.4	5,217
Mozambique	0.92	2.03	0.97	2.03	37,814
Namibia	-	-	-	-	61,560
South Africa	0.03	0.06	0.04	0.06	83,549
Swaziland	-	-	-	-	939
Tanzania	0.32	1.18	0.33	1.42	38,264
Zambia	-	-	-	-	40,313
Zimbabwe	-	-	-	-	21,787
Total	**0.28**	**1.13**	**0.40**	**1.17**	**407,657**

[1] includes moderately to very suitable land

TABLE 6.10

Percentage of suitable[1] land for sugarcane intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		‘000 ha
Angola	0.18	2.54	0.13	3.21	9,074
Botswana	-	-	-	-	9,368
Lesotho	-	-	-	-	650
Malawi	0.69	3.30	0.69	3.3	2,142
Mozambique	0.64	1.84	0.59	1.84	12,409
Namibia	-	-	-	-	3,561
South Africa	0.18	0.33	0.13	0.33	21,856
Swaziland	-	-	-	-	311
Tanzania	2.1	6.82	2.74	8.25	18,612
Zambia	-	-	-	-	5,432
Zimbabwe	-	-	-	-	10,700
Total	**0.58**	**1.99**	**0.68**	**2.34**	**94,116**

[1] includes moderately to very suitable land

TABLE 6.11

Sugarcane production ('000 tons) in suitable[1] land available for expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	3,406	22,409	6,227	22,944
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	90	1,083	90	1,083
Mozambique	1,981	5,586	2,169	5,586
Namibia	-	-	-	-
South Africa	142	347	168	347
Swaziland	-	-	-	-
Tanzania	875	3,435	971	4,129
Zambia	-	-	-	-
Zimbabwe	-	-	-	-
Total	**6,494**	**32,860**	**9,625**	**34,089**

[1] includes moderately to very suitable land

TABLE 6.12

Sugarcane production ('000 tons) in suitable[1] land available for intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	96	1,450	105	1,811
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	95	467	95	467
Mozambique	489	1,607	489	1,607
Namibia	-	-	-	-
South Africa	212	433	212	433
Swaziland	-	-	-	-
Tanzania	3,339	10,438	4,170	12,938
Zambia	-	-	-	-
Zimbabwe	-	-	-	-
Total	**4,231**	**14,395**	**5,071**	**17,256**

[1] includes moderately to very suitable land

FIGURE 6.15

Potential land for sugarcane expansion under tillage-based production at high level of inputs by suitability index

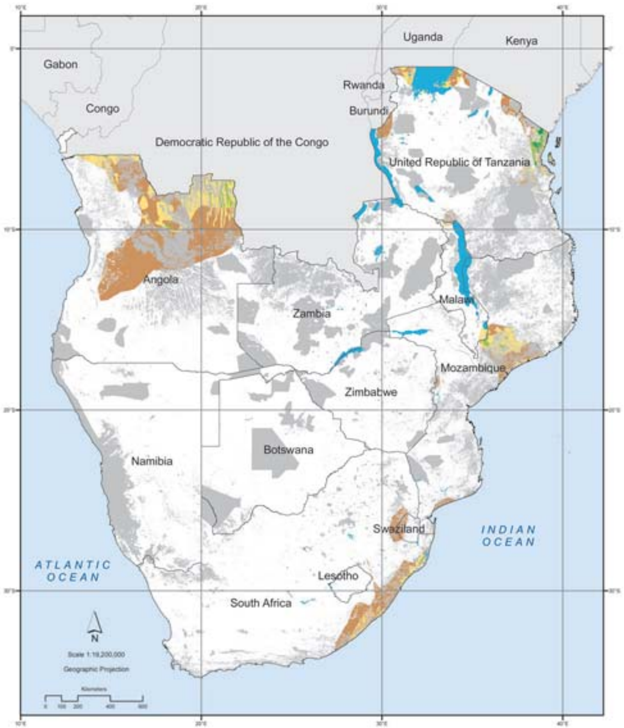
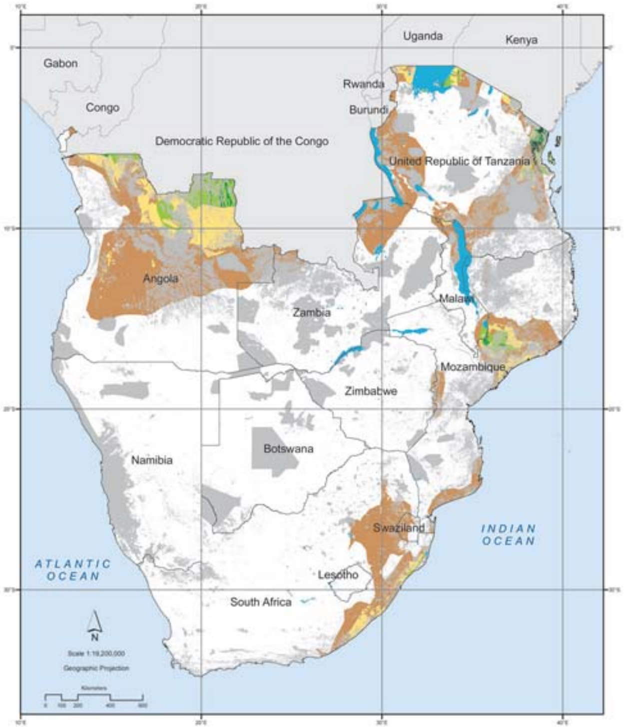


FIGURE 6.16

Potential land for sugarcane expansion under Conservation Agriculture at high level of inputs by suitability index



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- ☐ Not Suitable
- ■ Excluded areas
- ■ Water bodies

6.1.3 Sweet sorghum

In the case of the sweet sorghum, the analysis was carried out for two different varieties: the lowland and the highland types.

The geographical distribution of the agro-climatic suitability of the sweet sorghum lowland at high- and low-input levels is shown for TA in Figure 6.17, and for CA in Figure 6.18. Distribution for sweet sorghum highland at high- and low-input levels is shown for TA in Figure 6.19, and for CA in Figure 6.20. As shown in Table 6.13, for sweet sorghum lowland production under TA, 55.74 percent of the total regional land area (676 million ha) is agro-climatically suitable, whereas under CA 60.04 percent of the total regional land area is suitable. In the case of sweet sorghum highland, agro-climatically suitable land is 13.55 percent under TA and 19.24 percent under CA (Table 6.15). The bulk of the agro-climatically suitable land for sweet sorghum lowland is located in the northern part of the study region in Tanzania, Angola, Zambia, Malawi, Mozambique and Zimbabwe. The highland variety is agro-climatically suitable mostly in Angola, Swaziland, Tanzania and Zambia (this last one under CA).

Regional suitable land for sweet sorghum lowland decreases by almost 30 percent under each configuration due to the soil and landform constraints (Table 6.14). In the case of highland sweet sorghum, regional suitable land drops to 7 percent on average between low- and high- input levels under TA, with more than 40 percent reduction, whereas under CA the suitable land drops around 13 percent at both input levels, with 30 percent reduction (Table 6.16).

Geographical distribution of the Land Suitability Index for sweet sorghum lowland at low-input level is shown in Figures 6.21 and 6.22 for TA and CA, respectively, and at high-input levels in Figures 6.23 and 6.24. For sweet sorghum highland at low-input levels, the Land Suitability Index is shown in Figures 6.25 and 6.26 for TA and CA, respectively, and at the high-input levels in Figures 6.27 and 6.28.

Once environmental constraints and other land use types have been subtracted, estimates of suitable land available for lowland sweet sorghum expansion and its potential production are presented in Tables 6.17 and 6.19. Tables 6.18 and 6.20 show suitable land and production assuming a policy of intensification. Figures 6.29 and 6.30 show the distribution of potential suitable land area for expansion with high-input levels under TA and CA, respectively. Data for highland sweet sorghum are presented in Tables 6.21 and 6.23 (expansion) and Tables 6.22 and 6.24 (intensification), and in Figures 6.31 and 6.32.

At low-input levels, there are almost 130 million ha of suitable land for expansion of lowland sweet sorghum under TA (corresponding to 543 million tonnes of juice), and slightly more than 155 million ha under CA (corresponding to almost 965 million tonnes of juice). Suitable land for expansion at high-input levels increases to 136 million ha under TA (corresponding to 2.4 billion tonnes) and around 161 million ha under CA (corresponding to 3.7 billion tonnes).

Suitable land for intensification of lowland sweet sorghum with low-level input is around 32 million ha under TA (corresponding to 138 million tonnes of juice) and 42 million ha under CA (corresponding to almost 650 million tonnes); with high-input levels there are 36 million ha under TA (corresponding to 262 million tonnes of juice) and almost 45 million ha under CA (corresponding to almost one billion tonnes).

Suitable land available for expansion of highland sweet sorghum under TA at low-input level is almost 27 million ha (corresponding to 162 million tonnes of juice) and slightly more than 50 million ha under CA at low-input levels (corresponding to more than 800 million tonnes of juice). Suitable land for expansion at high level of inputs increases to 31 million ha under TA (corresponding to 430 million tonnes) and around 51 million ha under CA (corresponding to 1.7 billion tonnes). Suitable land for intensification of highland sweet sorghum with low level of inputs is around 4 million ha under TA (corresponding to almost 25 million tonnes of juice) and 5 million ha under CA (corresponding to almost 120 million tonnes); with high level of inputs there are 8 million ha under TA (corresponding to 67 million tonnes of juice) and almost 8.8 million ha under CA (corresponding to almost 280 million tonnes of juice).

For both varieties of sweet sorghum, the amount of suitable land available for expansion is quite large: in the case of the highland it is almost double under CA.

Given the large amount of suitable and available land and consequently high potential juice production, especially under CA, sweet sorghum has great potential to meet any biofuel demand with relatively low impact on country food security. An analysis of technical feasibility and economic competitiveness for converting this feedstock into biofuel would be required before planning targets.

FIGURE 6.17

Agro-climatic suitability for sweet sorghum (lowland) under tillage-based production at high and low level

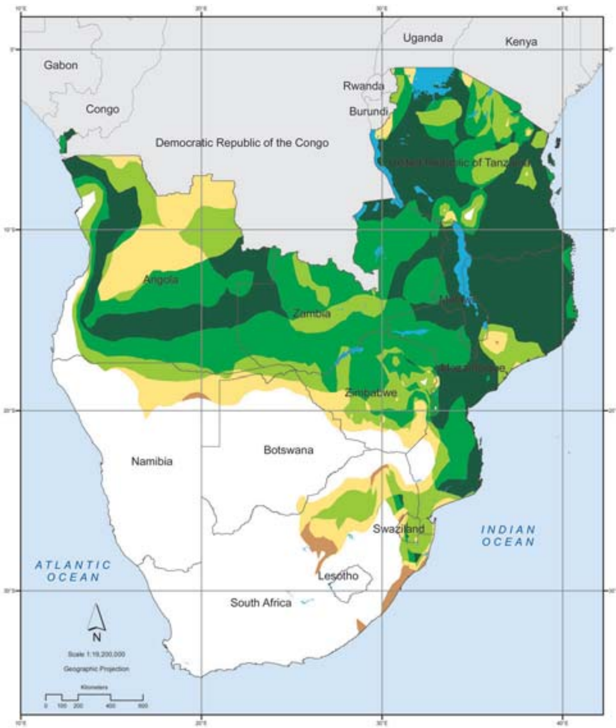
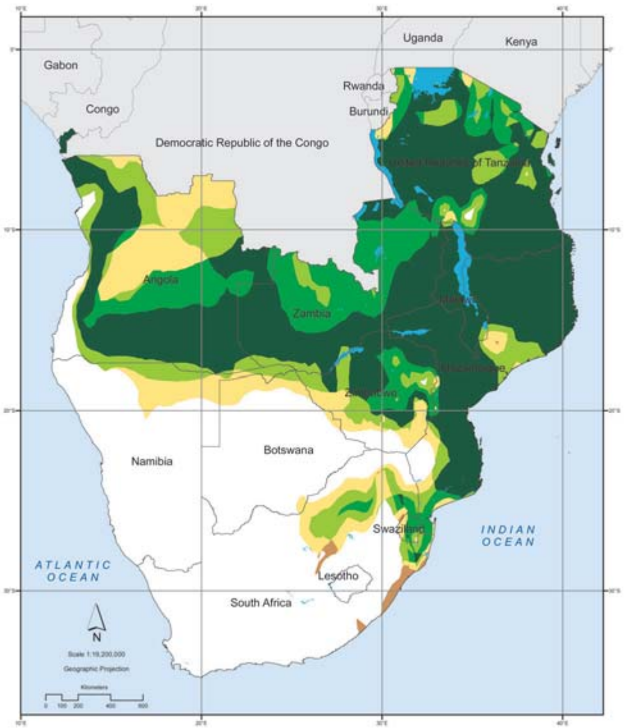


FIGURE 6.18

Agro-climatic suitability for sweet sorghum (lowland) under Conservation Agriculture at high and low level



🟩	Very Suitable (80-100%)
🟩	Suitable (60-80%)
🟩	Moderately Suitable (40-60%)
🟨	Marginally Suitable (20-40%)
🟫	Very Marginally Suitable (< 20%)
☐	Not Suitable
🟦	Water bodies

TABLE 6.13

Percentage of agro-climatic suitable[1] land for sweet sorghum (lowland)

Country	Tillage-based production	Conservation Agriculture	Total Land Area
	With low and high input	With low and high input	'000 ha
Angola	74.68	75.01	124,945
Botswana	1.03	11.36	57,178
Lesotho	-	-	2,968
Malawi	99.40	99.40	9,483
Mozambique	91.45	93.33	77,636
Namibia	6.71	16.26	82,083
South Africa	7.44	12.63	120,067
Swaziland	69.46	72.48	1,637
Tanzania	97.20	97.34	88,107
Zambia	100.00	100.00	73,638
Zimbabwe	72.27	90.52	38,318
Total	**55.74**	**60.04**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.14

Percentage of suitable[1] land for sweet sorghum (lowland)

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	36.98	49.65	39.41	50.28	124,945
Botswana	0.08	1.80	0.23	2.18	57,178
Lesotho	-	-	-	-	2,968
Malawi	94.44	99.29	94.47	99.30	9,483
Mozambique	51.64	59.51	55.78	63.24	77,636
Namibia	0.03	4.24	0.08	4.34	82,083
South Africa	3.52	7.65	4.03	8.34	120,067
Swaziland	17.82	26.96	26.16	39.05	1,637
Tanzania	59.17	70.91	67.44	75.05	88,107
Zambia	98.28	99.95	98.28	99.95	73,638
Zimbabwe	30.46	45.73	36.62	50.67	38,318
Total	**34.91**	**42.21**	**37.39**	**43.77**	**676,060**

[1] includes moderately to very suitable land

FIGURE 6.19

Agro-climatic suitability for sweet sorghum (highland) under tillage-based production at high and low level of inputs

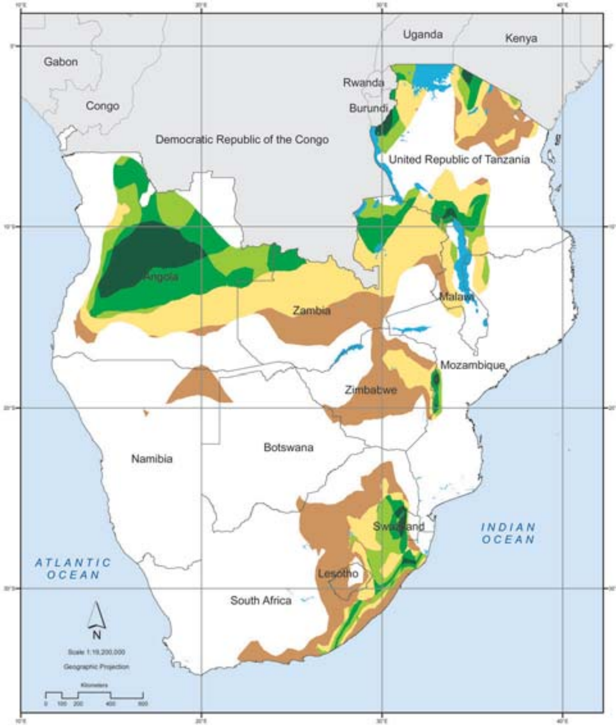
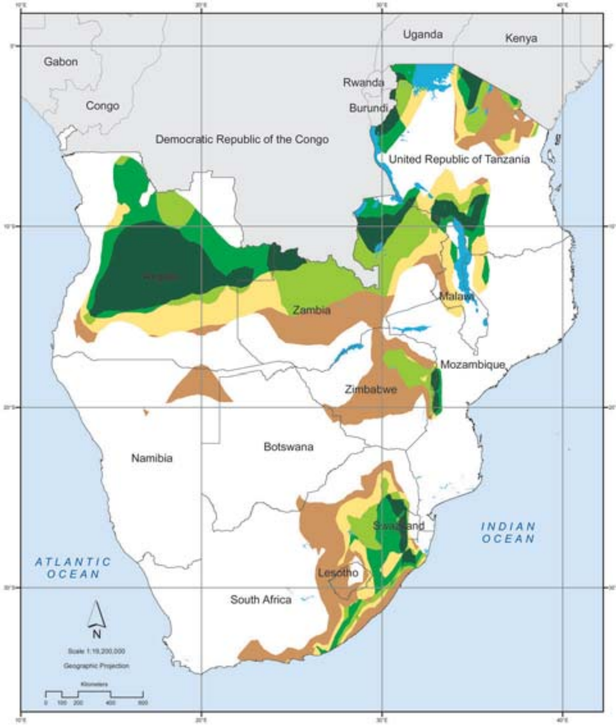


FIGURE 6.20

Agro-climatic suitability for sweet sorghum (highland) under Conservation Agriculture at high and low level of inputs



■ Very Suitable (80-100%)
🟩 Suitable (60-80%)
🟩 Moderately Suitable (40-60%)
🟨 Marginally Suitable (20-40%)
🟫 Very Marginally Suitable (< 20%)
⬜ Not Suitable
🟦 Water bodies

TABLE 6.15

Percentage of agro-climatic suitable[1] land for sweet sorghum (highland)

Country	Tillage-based production	Conservation Agriculture	Total Land Area
	With low and High input	With low and high input	'000 ha
Angola	44.86	46.61	124,945
Botswana	-	-	57,178
Lesotho	-	-	2,968
Malawi	8.03	8.03	9,483
Mozambique	2.07	2.14	77,636
Namibia	-	-	82,083
South Africa	8.79	11.96	120,067
Swaziland	38.15	43.73	1,637
Tanzania	14.32	21.72	88,107
Zambia	12.27	42.43	73,638
Zimbabwe	0.88	10.33	38,318
Total	**13.55**	**19.24**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.16

Percentage of suitable[1] land for sweet sorghum (highland)

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	20.85	32.16	24.16	32.22	124,945
Botswana	-	-	-	-	57,178
Lesotho	-	-	-	-	2,968
Malawi	5.17	7.97	5.19	7.97	9,483
Mozambique	0.60	1.36	0.69	1.36	77,636
Namibia	-	-	-	-	82,083
South Africa	4.20	7.49	4.79	8.11	120,067
Swaziland	22.14	30.45	23.12	30.56	1,637
Tanzania	5.87	13.58	8.19	14.73	88,107
Zambia	11.21	33.56	11.21	33.56	73,638
Zimbabwe	0.36	3.27	0.36	3.35	38,318
Total	**6.80**	**13.23**	**7.83**	**13.50**	**676,060**

[1] includes moderately to very suitable land

FIGURE 6.21

Land suitability index for sweet sorghum (lowland) under tillage-based production at low level of inputs

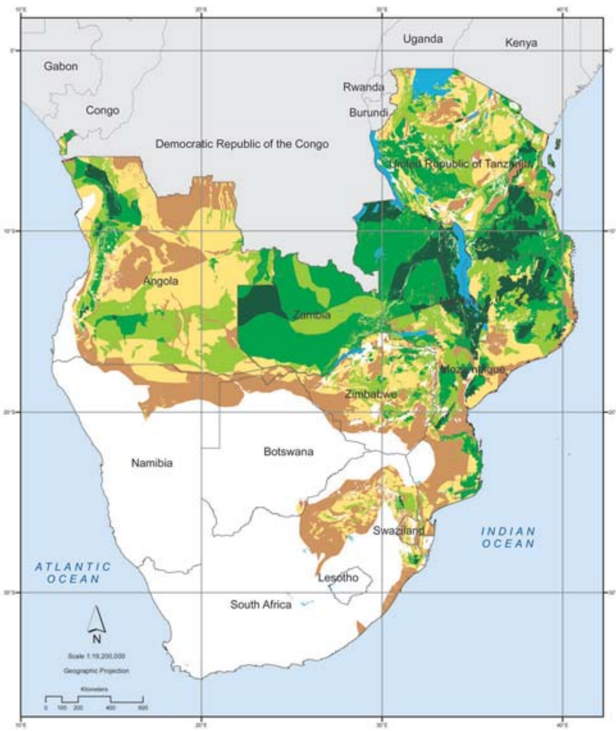
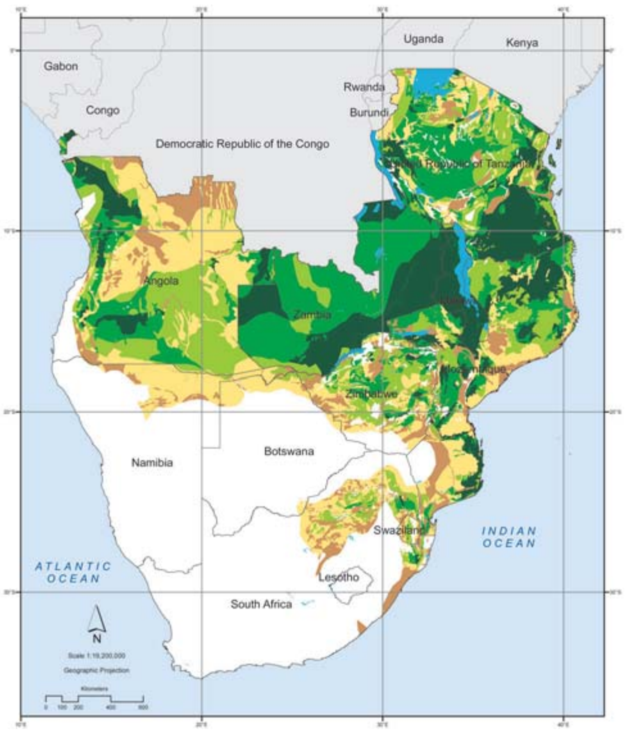


FIGURE 6.22

Land suitability index for sweet sorghum (lowland) under Conservation Agriculture at low level of inputs



■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
□ Not Suitable
■ Water bodies

FIGURE 6.23

Land suitability index for sweet sorghum (lowland) under tillage-based production at high level of inputs

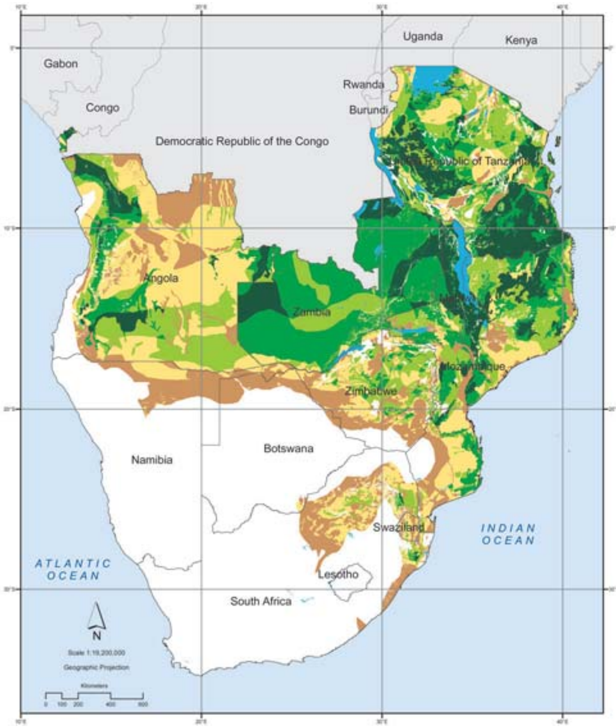
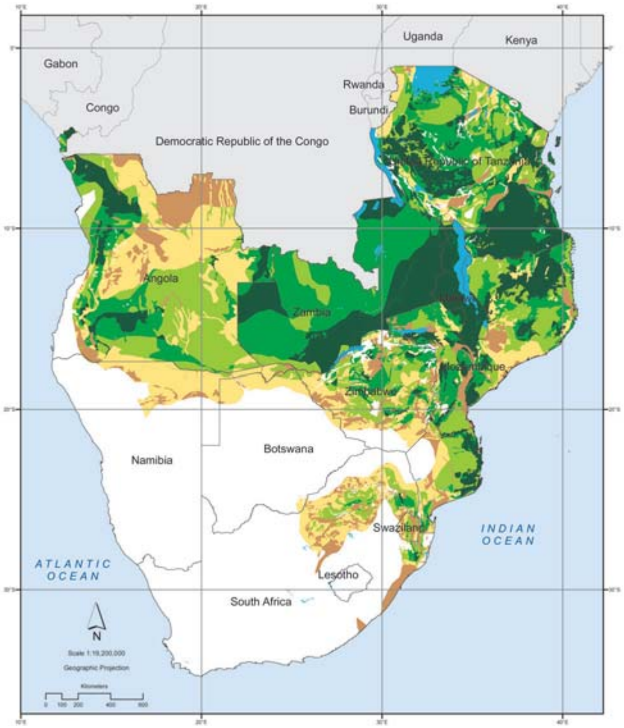


FIGURE 6.24

Land suitability index for sweet sorghum (lowland) under Conservation Agriculture at high level of inputs



■	Very Suitable (80-100%)
■	Suitable (60-80%)
■	Moderately Suitable (40-60%)
■	Marginally Suitable (20-40%)
■	Very Marginally Suitable (< 20%)
□	Not Suitable
■	Water bodies

FIGURE 6.25

Land suitability index for sweet sorghum (highland) under tillage-based production at low level of inputs

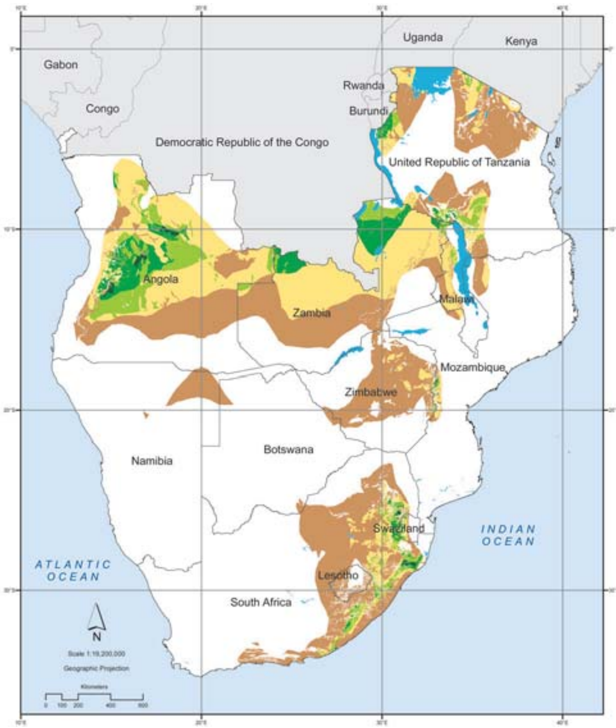
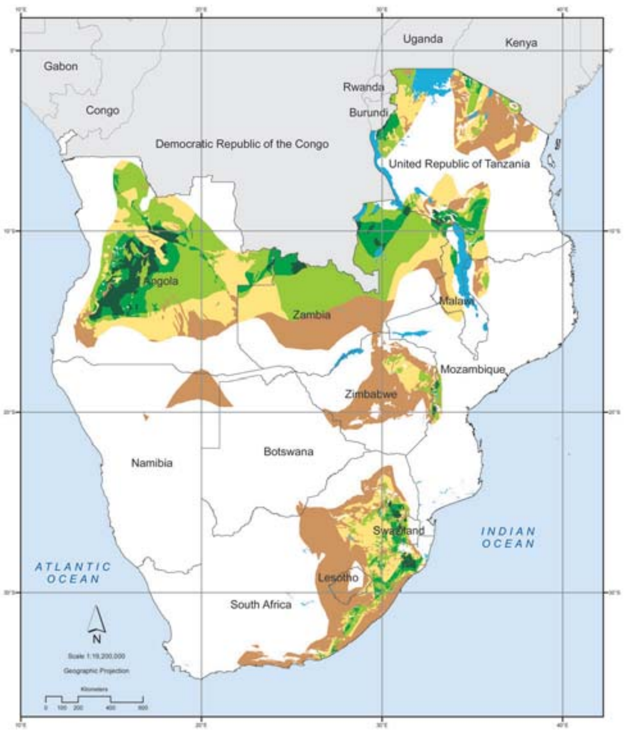


FIGURE 6.26

Land suitability index for sweet sorghum (highland) under Conservation Agriculture at low level of inputs



- 🟩 Very Suitable (80-100%)
- 🟩 Suitable (60-80%)
- 🟩 Moderately Suitable (40-60%)
- 🟨 Marginally Suitable (20-40%)
- 🟫 Very Marginally Suitable (< 20%)
- ⬜ Not Suitable
- 🟦 Water bodies

FIGURE 6.27
Land suitability index for sweet sorghum (highland) under tillage-based production at high level of inputs

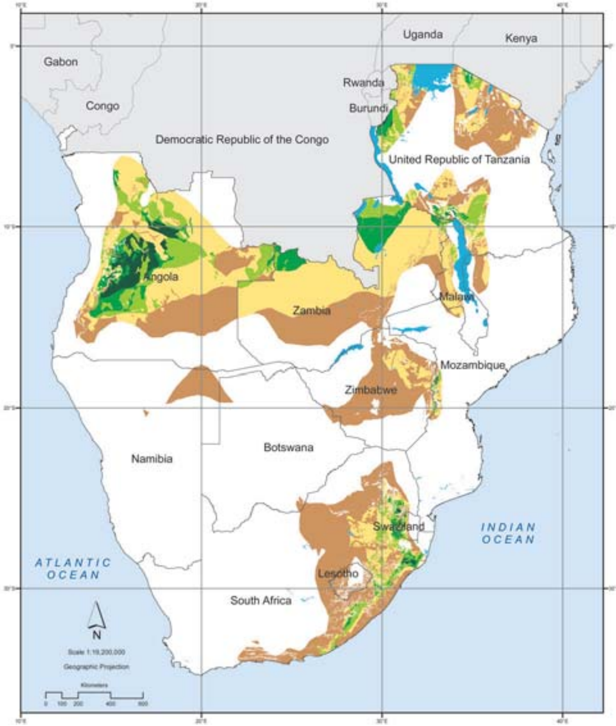
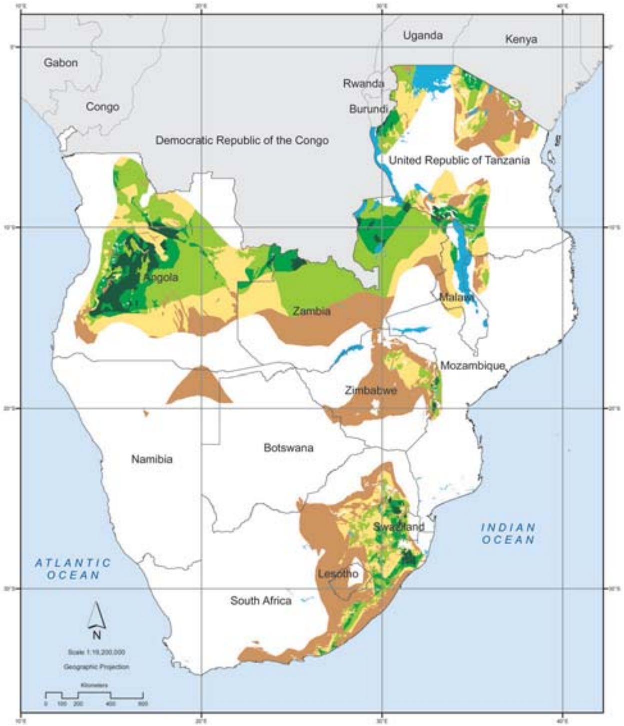


FIGURE 6.28
Land suitability index for sweet sorghum (highland) under Conservation Agriculture at high level of inputs



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- □ Not Suitable
- ■ Water bodies

TABLE 6.17

Percentage of suitable[1] land for sweet sorghum (lowland) expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	38.96	52.83	41.64	53.30	79,333
Botswana	0.04	1.15	0.19	1.54	36,581
Lesotho	-	-	-	-	2,300
Malawi	96.61	99.53	96.65	99.55	5,217
Mozambique	53.19	60.58	57.17	64.16	37,814
Namibia	0.03	4.12	0.10	4.22	61,560
South Africa	2.80	6.13	3.23	6.74	83,549
Swaziland	17.34	26.12	25.03	39.42	939
Tanzania	57.06	69.43	66.08	74.19	38,264
Zambia	98.91	99.94	98.91	99.94	40,313
Zimbabwe	32.71	48.04	39.44	53.43	21,787
Total	**31.26**	**38.18**	**33.49**	**39.55**	**407,657**

[1] includes moderately to very suitable land

TABLE 6.18

Percentage of suitable[1] land for sweet sorghum (lowland) intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	50.96	67.37	54.61	68.29	9,074
Botswana	0.11	3.56	0.25	4.03	9,368
Lesotho	-	-	-	-	650
Malawi	95.29	99.05	95.30	99.06	2,142
Mozambique	50.00	58.84	55.61	62.84	12,409
Namibia	0.05	21.69	0.06	21.71	3,561
South Africa	4.99	11.61	5.63	12.59	21,856
Swaziland	22.89	32.60	31.57	41.76	311
Tanzania	53.33	66.43	63.96	72.89	18,612
Zambia	96.74	99.97	96.74	99.97	5,432
Zimbabwe	32.88	48.15	38.65	52.35	10,700
Total	**34.79**	**44.87**	**38.83**	**47.55**	**94,116**

[1] includes moderately to very suitable land

TABLE 6.19

Sweet sorghum (lowland) production (‘000 tons) in suitable[1] land available for expansion

Country	**Tillage-based production**	**Conservation Agriculture**	**Tillage-based production**	**Conservation Agriculture**
	With low input		With high input	
Angola	117,684	244,840	548,813	921,252
Botswana	37	1,494	703	7,623
Lesotho	-	-	-	-
Malawi	28,471	41,296	113,096	152,144
Mozambique	93,777	154,424	407,009	604,521
Namibia	51	9,660	610	36,502
South Africa	7,005	23,179	32,494	93,481
Swaziland	513	1,389	3,124	7,246
Tanzania	93,943	176,821	492,098	736,301
Zambia	176,330	256,621	700,150	945,476
Zimbabwe	24,793	55,091	119,802	226,288
Total	**542,604**	**964,815**	**2,417,899**	**3,730,834**

[1] includes moderately to very suitable land

TABLE 6.20

Sweet sorghum (lowland) production (‘000 tons) in suitable[1] land available for intensification

Country	**Tillage-based production**	**Conservation Agriculture**	**Tillage-based production**	**Conservation Agriculture**
	With low input		With high input	
Angola	17,938	82,254	36,787	139,005
Botswana	27	241	1,189	5,001
Lesotho	-	-	-	-
Malawi	11,466	45,533	16,746	61,683
Mozambique	28,111	126,309	48,158	193,147
Namibia	5	23	3,013	11,113
South Africa	3,123	14,160	11,189	44,628
Swaziland	234	1,392	596	2,689
Tanzania	41,603	223,960	80,296	344,300
Zambia	23,372	92,817	36,530	134,592
Zimbabwe	12,267	58,116	27,656	111,348
Total	**138,146**	**644,805**	**262,160**	**1,047,506**

[1] includes moderately to very suitable land

FIGURE 6.29

Potential land for sweet sorghum (lowland) expansion under tillage-based production at high level of inputs by suitability index

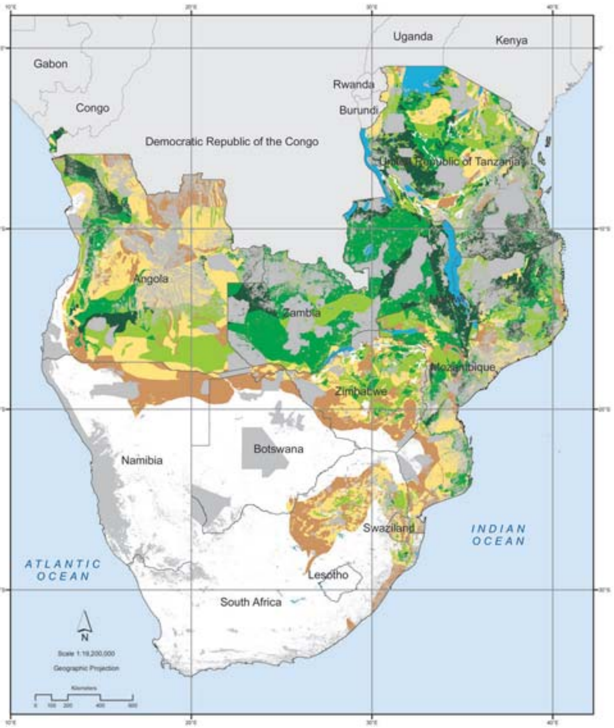
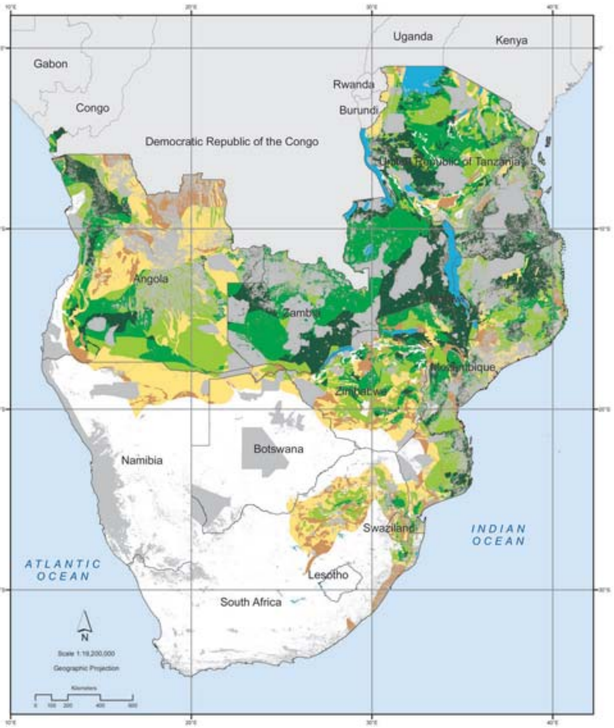


FIGURE 6.30

Potential land for sweet sorghum (lowland) expansion under Conservation Agriculture at high level of inputs by suitability index



■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
□ Not Suitable
■ Excluded areas
■ Water bodies

TABLE 6.21

Percentage of suitable[1] land for sweet sorghum (highland) expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	20.60	29.62	23.79	29.70	79,333
Botswana	-	-	-	-	36,581
Lesotho	-	-	-	-	2,300
Malawi	4.17	6.01	4.17	6.01	5,217
Mozambique	0.42	1.04	0.51	1.04	37,814
Namibia	-	-	-	-	61,560
South Africa	2.95	5.26	3.28	5.54	83,549
Swaziland	21.28	27.85	21.91	27.97	939
Tanzania	6.48	15.08	8.72	16.21	38,264
Zambia	13.23	36.90	13.23	36.90	40,313
Zimbabwe	0.19	3.56	0.19	3.65	21,787
Total	**6.68**	**12.33**	**7.59**	**12.52**	**407,657**

[1] includes moderately to very suitable land

TABLE 6.22

Percentage of suitable[1] land for sweet sorghum (highland) intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	12.45	18.04	14.47	18.16	9,074
Botswana	-	-	-	-	9,368
Lesotho	-	-	-	-	650
Malawi	5.68	7.58	5.69	7.58	2,142
Mozambique	0.30	0.63	0.33	0.63	12,409
Namibia	-	-	-	-	3,561
South Africa	7.14	13.22	8.38	15.72	21,856
Swaziland	26.83	41.45	29.40	41.62	311
Tanzania	4.34	10.93	5.51	12.21	18,612
Zambia	9.12	14.88	9.12	14.88	5,432
Zimbabwe	0.22	2.39	0.22	2.44	10,700
Total	**4.53**	**8.49**	**5.25**	**9.34**	**94,116**

[1] includes moderately to very suitable land

TABLE 6.23

Sweet sorghum (highland) production ('000 tons) in suitable[1] land available for expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	97,827	507,312	216,587	835,556
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	1,218	4,877	2,693	10,357
Mozambique	778	4,006	3,032	11,667
Namibia	-	-	-	-
South Africa	14,135	65,404	36,825	148,547
Swaziland	1,254	6,270	2,878	11,106
Tanzania	14,473	82,625	48,749	201,006
Zambia	32,330	129,329	114,008	438,510
Zimbabwe	238	1,055	5,199	20,508
Total	**162,253**	**800,878**	**429,971**	**1,677,257**

[1] includes moderately to very suitable land

TABLE 6.24

Sweet sorghum (highland) production ('000 tons) in suitable[1] land available for intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	7,071	36,955	15,923	61,672
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	691	2,768	1,389	5,343
Mozambique	180	862	615	2,366
Namibia	-	-	-	-
South Africa	8,559	41,158	22,463	101,104
Swaziland	532	2,755	1,319	5,088
Tanzania	4,287	23,999	16,220	70,098
Zambia	2,941	11,766	6,899	26,538
Zimbabwe	157	664	1,768	6,921
Total	**24,418**	**120,927**	**66,596**	**279,130**

[1] includes moderately to very suitable land

FIGURE 6.31

Potential land for sweet sorghum (highland) expansion under tillage-based production at high level of inputs by suitability index

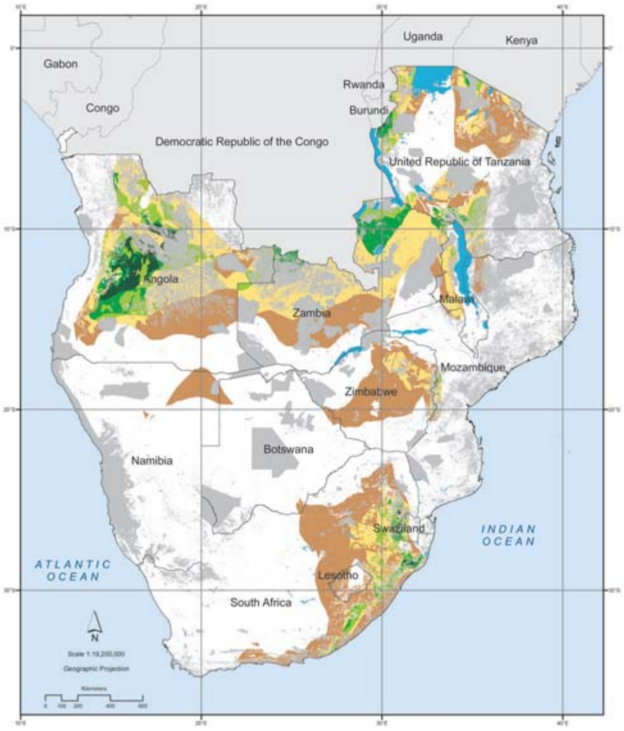
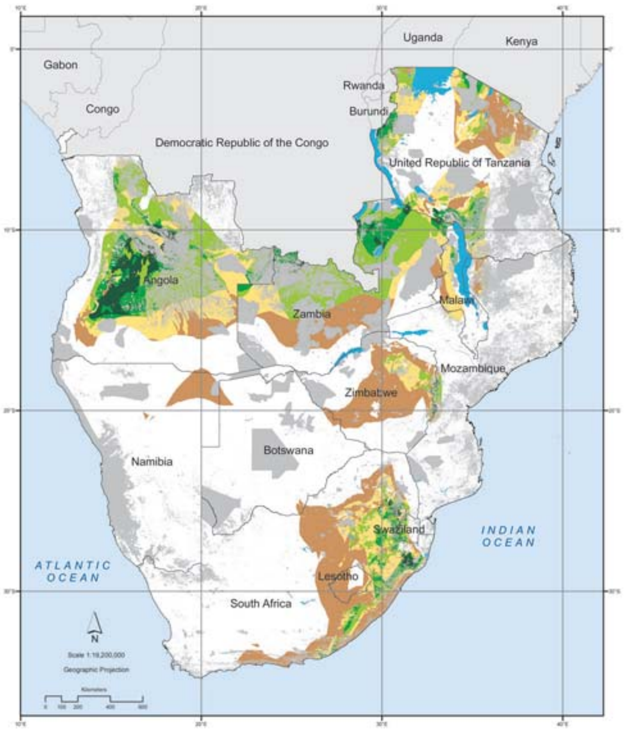


FIGURE 6.32

Potential land for sweet sorghum (highland) expansion under Conservation Agriculture at high level of inputs by suitability index



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- □ Not Suitable
- ■ Excluded areas
- ■ Water bodies

6.2 CROPS FOR BIODIESEL PRODUCTION

The crops presented in this section, namely oil palm (tall and compact) and sunflower among others, may be considered for biodiesel production.

6.2.1 Oil Palm

Analysis was carried out for two different varieties of oil palm: tall and compact.

The geographical distribution of the agro-climatic suitability of oil palm tall at high- and low-input levels is shown for TA in Figure 6.33, and for CA in Figure 6.34. Distribution of oil palm compact at high- and low-input levels is shown for TA in Figure 6.35, and for CA in Figure 6.36. As can be seen in Table 6.25, for oil palm tall production under TA, 0.21 percent of the total regional land area (676 million ha) is agro-climatically suitable, whereas under CA, 0.38 percent of the total regional land area is suitable. In the case of oil palm compact, agro-climatically suitable land is 0.28 percent under TA and 2.49 percent under CA (Table 6.27). The area in every LUT is very small, mostly as the result of limited moisture availability.

At low-input levels, regional suitable land for oil palm tall drops to 0.10 percent under TA and 0.20 percent under CA Table 6.26; for oil palm compact the figures drop to 0.14 and 1.07, respectively Table 6.28. The data are very similar at high-input levels as well, except for palm oil compact under CA, where it is 1.88 percent.

Geographical distribution of the Land Suitability Index for oil palm tall at high- and low-input levels (the differences are minimal) is shown in Figures 6.37 and 6.38 for TA and CA, respectively. For oil palm compact at high- and low-input levels, the Land Suitability Index is shown in Figures 6.39 and 6.40 for TA and CA, respectively.

After the environmental constraints and other land use are considered and that land has been subtracted, estimates of suitable land available and its potential production for oil palm tall expansion are presented in Tables 6.29 and 6.31. Tables 6.30 and 6.32 show the suitable land and its potential production assuming a policy of intensification. Figures 6.41 and 6.42 show the distribution of potential suitable land area for expansion with high-input levels under TA and CA, respectively. Oil palm compact data are provided in: Tables 6.33 and 6.35 (expansion); Tables 6.34 and 6.36 (intensification); Figures 6.43 and 6.44.

At high- and low-input levels, there is very limited suitable land in the region for expansion of oil palm tall: 80,000 ha under TA (corresponding to 238,000 tonnes of oil with low inputs and almost 1.3 million tonnes with high inputs) and ranging from 160,000–200,000 ha under CA (corresponding to 700,000 tonnes of oil with low inputs and almost 4.3 million tonnes with high inputs).

More suitable land is available for oil palm tall intensification, ranging from 330,000 to almost 700,000 ha with low-input levels under TA and CA, respectively. The corresponding production ranges from 1.2–3.8 million tonnes of oil. At high-input levels, the range increases slightly to 400,000–800,000 ha, with a considerable increase in production: 6.5 million tonnes under TA and 19.6 million tonnes under CA.

In the case of the oil palm compact, opportunity for land expansion is envisaged under CA with three million ha of suitable land available at low-input levels and 5.7 million ha at high-input levels. Under TA the extension are ranging from 80,000 to 120,000 ha. In the case of intensification the potential suitable land under CA is three times higher than the one under TA: 1.5 million ha vs. 500,000 ha under low-input levels and 1.7 million ha vs. 555,000 ha under high-input levels.

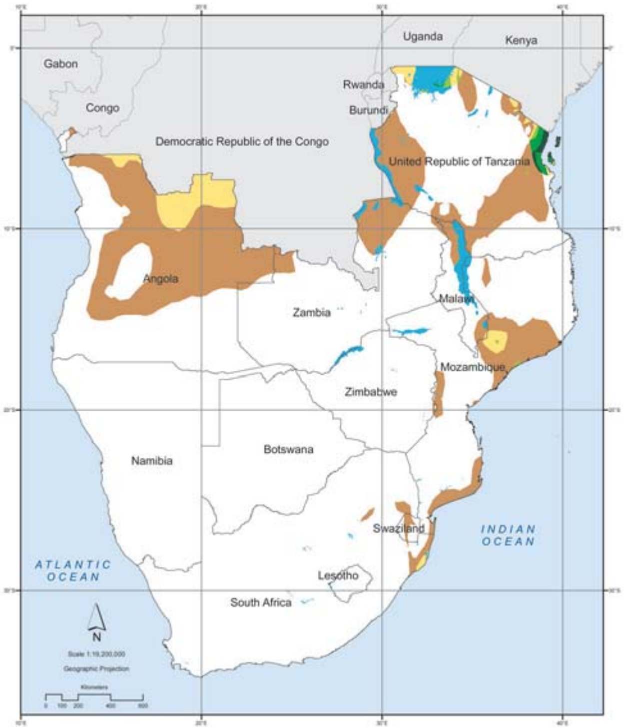
As in the case of sugarcane, oil palm does not represent a feedstock that could be used to cover biodiesel country-specific policy targets. Furthermore, according to the trade figures in FAOSTAT, the countries in the study region are net importers for palm oil, which means that current production is not sufficient to satisfy internal demand.

FIGURE 6.33

Agro-climatic suitability for oil palm (tall) under tillage-based production at high and low level of inputs

FIGURE 6.34

Agro-climatic suitability for oil palm (tall) under Conservation Agriculture at high and low level of inputs



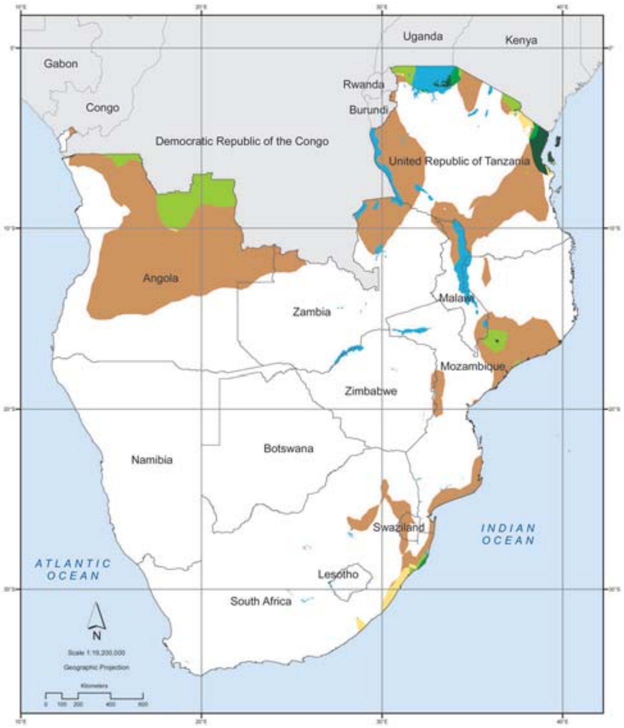
- 🟩 Very Suitable (80-100%)
- 🟩 Suitable (60-80%)
- 🟩 Moderately Suitable (40-60%)
- 🟨 Marginally Suitable (20-40%)
- 🟫 Very Marginally Suitable (< 20%)
- ☐ Not Suitable
- 🟦 Water bodies

FIGURE 6.35

Agro-climatic suitability for oil palm (compact) under tillage-based production at high and low level of inputs

FIGURE 6.36

Agro-climatic suitability for oil palm (compact) under Conservation Agriculture at high and low level of inputs



■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
☐ Not Suitable
■ Water bodies

TABLE 6.25

Percentage of agro-climatic suitable[1] land for oil palm (tall)

Country	Tillage-based production	Conservation Agriculture	Total Land Area
	With low and high input	With low and high input	'000 ha
Angola	-	-	124,945
Botswana	-	-	57,178
Lesotho	-	-	2,968
Malawi	-	-	9,483
Mozambique	-	0.16	77,636
Namibia	-	-	82,083
South Africa	-	0.01	120,067
Swaziland	-	-	1,637
Tanzania	1.60	2.80	88,107
Zambia	-	-	73,638
Zimbabwe	-	-	38,318
Total	**0.21**	**0.38**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.26

Percentage of suitable[1] land for oil palm (tall)

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	-	-	-	-	124,945
Botswana	-	-	-	-	57,178
Lesotho	-	-	-	-	2,968
Malawi	-	-	-	-	9,483
Mozambique	-	0.02	-	0.02	77,636
Namibia	-	-	-	-	82,083
South Africa	-	-	-	-	120,067
Swaziland	-	-	-	-	1,637
Tanzania	0.75	1.55	0.94	1.84	88,107
Zambia	-	-	-	-	73,638
Zimbabwe	-	-	-	-	38,318
Total	**0.10**	**0.20**	**0.12**	**0.24**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.27

Percentage of agro-climatic suitable[1] land for oil palm (compact)

Country	Tillage-based production	Conservation Agriculture	Total Land Area
	With low and high input	With low and high input	'000 ha
Angola	-	8.20	124,945
Botswana	-	-	57,178
Lesotho	-	-	2,968
Malawi	-	0.58	9,483
Mozambique	0.04	2.05	77,636
Namibia	-	-	82,083
South Africa	0.13	0.28	120,067
Swaziland	-	-	1,637
Tanzania	1.93	5.22	88,107
Zambia	-	-	73,638
Zimbabwe	-	-	38,318
Total	**0.28**	**2.49**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.28

Percentage of suitable[1] land for oil palm (compact)

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		'000 ha
Angola	-	2.90	-	6.97	124,945
Botswana	-	-	-	-	57,178
Lesotho	-	-	-	-	2,968
Malawi	-	0.57	-	0.57	9,483
Mozambique	0.01	1.17	0.01	1.26	77,636
Namibia	-	-	-	-	82,083
South Africa	0.01	0.11	0.02	0.11	120,067
Swaziland	-	-	-	-	1,637
Tanzania	1.04	2.88	1.22	3.21	88,107
Zambia	-	-	-	-	73,638
Zimbabwe	-	-	-	-	38,318
Total	**0.14**	**1.07**	**0.16**	**1.88**	**676,060**

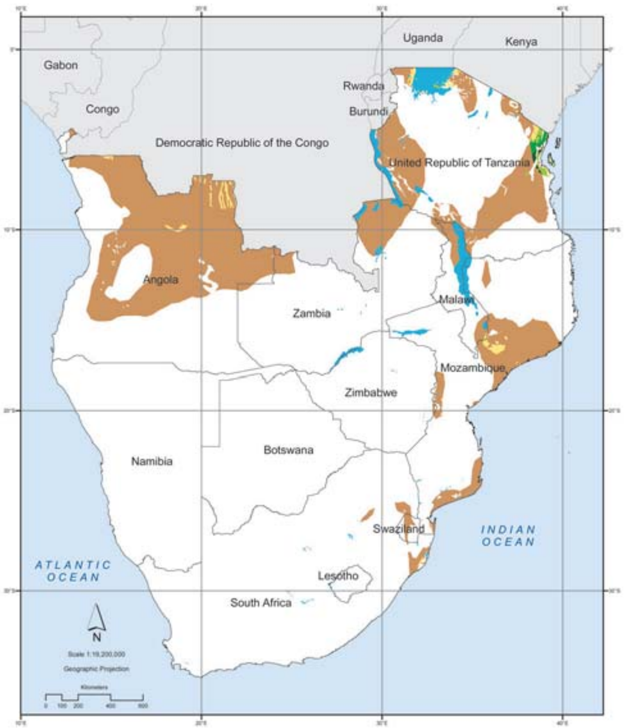
[1] includes moderately to very suitable land

FIGURE 6.37

Land suitability index for oil palm (tall) under tillage-based production at high and low level of inputs

FIGURE 6.38

Land suitability index for oil palm (tall) under Conservation Agriculture at high and low level of inputs



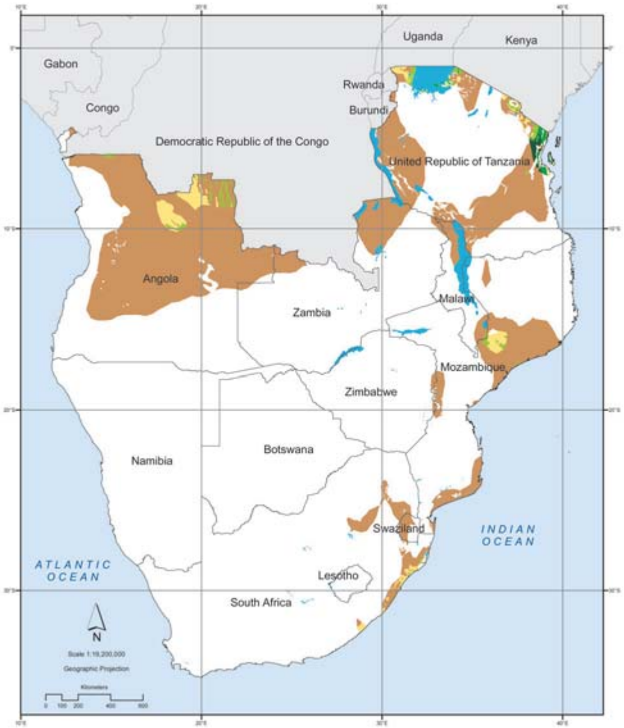
■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
□ Not Suitable
■ Water bodies

FIGURE 6.39

Land suitability index for oil palm (compact) under tillage-based production at high and low level of inputs

FIGURE 6.40

Land suitability index for oil palm (compact) under Conservation Agriculture at high and low level of inputs



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- □ Not Suitable
- ■ Water bodies

TABLE 6.29

Percentage of suitable[1] land for oil palm (tall) expansion

Country	**Tillage-based production**	**Conservation Agriculture**	**Tillage-based production**	**Conservation Agriculture**	**Total Land Area**
	With low input		With high input		'000 ha
Angola	-	-	-	-	79,333
Botswana	-	-	-	-	36,581
Lesotho	-	-	-	-	2,300
Malawi	-	-	-	-	5,217
Mozambique	-	0.02	-	0.02	37,814
Namibia	-	-	-	-	61,560
South Africa	-	-	-	-	83,549
Swaziland	-	-	-	-	939
Tanzania	0.16	0.36	0.21	0.46	38,264
Zambia	-	-	-	-	40,313
Zimbabwe	-	-	-	-	21,787
Total	**0.02**	**0.04**	**0.02**	**0.05**	**407,657**

[1] includes moderately to very suitable land

TABLE 6.30

Percentage of suitable[1] land for oil palm (tall) intensification

Country	**Tillage-based production**	**Conservation Agriculture**	**Tillage-based production**	**Conservation Agriculture**	**Total Land Area**
	With low input		With high input		'000 ha
Angola	-	-	-	-	9,074
Botswana	-	-	-	-	9,368
Lesotho	-	-	-	-	650
Malawi	-	-	-	-	2,142
Mozambique	-	-	-	-	12,409
Namibia	-	-	-	-	3,561
South Africa	-	-	-	-	21,856
Swaziland	-	-	-	-	311
Tanzania	1.84	3.70	2.26	4.17	18,612
Zambia	-	-	-	-	5,432
Zimbabwe	-	-	-	-	10,700
Total	**0.36**	**0.73**	**0.45**	**0.83**	**94,116**

[1] includes moderately to very suitable land

TABLE 6.31

Oil palm (tall) production ('000 tons) in suitable[1] land available for expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	-	-	-	-
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	-	-	-	-
Mozambique	-	21	-	99
Namibia	-	-	-	-
South Africa	-	-	-	-
Swaziland	-	-	-	-
Tanzania	238	687	1,273	4,134
Zambia	-	-	-	-
Zimbabwe	-	-	-	-
Total	**238**	**708**	**1,273**	**4,233**

[1] includes moderately to very suitable land

TABLE 6.32

Oil palm (tall) production ('000 tons) in suitable[1] land available for intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	-	-	-	-
Botswana	-	-	-	-
Lesotho	-	-	-	-
Malawi	-	-	-	-
Mozambique	-	1	-	4
Namibia	-	-	-	-
South Africa	-	-	-	-
Swaziland	-	-	-	-
Tanzania	1,255	3,753	6,573	19,656
Zambia	-	-	-	-
Zimbabwe	-	-	-	-
Total	**1,255**	**3,754**	**6,573**	**19,660**

[1] includes moderately to very suitable land

FIGURE 6.41

Potential land for oil palm (tall) expansion under tillage-based production at high level of inputs by suitability index

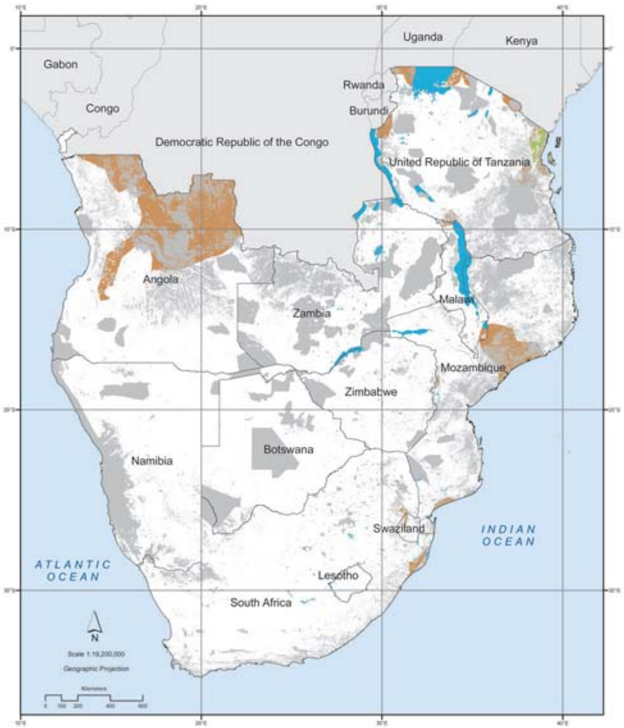
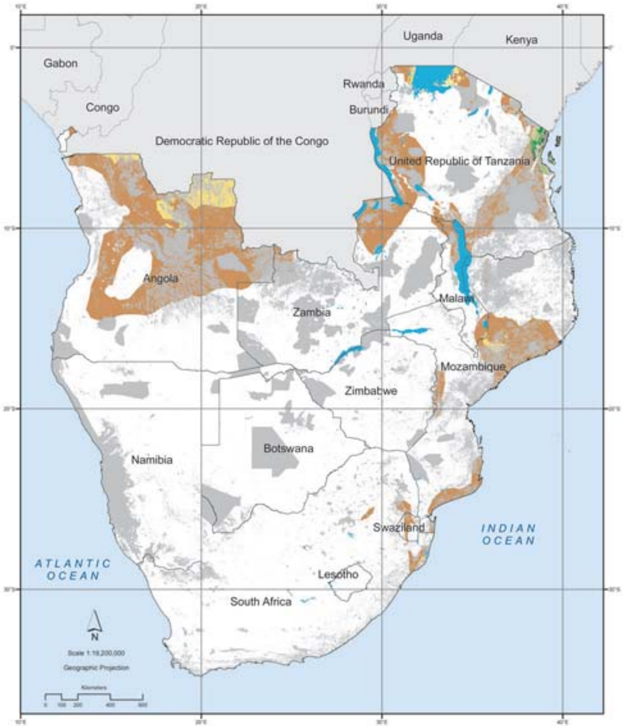


FIGURE 6.42

Potential land for oil palm (tall) expansion under Conservation Agriculture at high level of inputs by suitability index



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- □ Not Suitable
- ■ Excluded areas
- ■ Water bodies

TABLE 6.33

Percentage of suitable[1] land for oil palm (compact) expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		‘000 ha
Angola	-	2.65	-	5.81	79,333
Botswana	-	-	-	-	36,581
Lesotho	-	-	-	-	2,300
Malawi	-	0.34	-	0.34	5,217
Mozambique	0.01	1.11	0.01	1.25	37,814
Namibia	-	-	-	-	61,560
South Africa	-	0.05	-	0.05	83,549
Swaziland	-	-	-	-	939
Tanzania	0.24	1.30	0.31	1.43	38,264
Zambia	-	-	-	-	40,313
Zimbabwe	-	-	-	-	21,787
Total	**0.02**	**0.76**	**0.03**	**1.40**	**407,657**

[1] includes moderately to very suitable land

TABLE 6.34

Percentage of suitable[1] land for oil palm (compact) intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area
	With low input		With high input		‘000 ha
Angola	-	0.75	-	2.00	9,074
Botswana	-	-	-	-	9,368
Lesotho	-	-	-	-	650
Malawi	-	0.78	-	0.78	2,142
Mozambique	-	0.69	-	0.70	12,409
Namibia	-	-	-	-	3,561
South Africa	0.05	0.29	0.09	0.29	21,856
Swaziland	-	-	-	-	311
Tanzania	2.59	6.47	2.89	7.07	18,612
Zambia	-	-	-	-	5,432
Zimbabwe	-	-	-	-	10,700
Total	**0.52**	**1.53**	**0.59**	**1.77**	**94,116**

[1] includes moderately to very suitable land

TABLE 6.35

Oil palm (compact) production ('000 tons) in suitable[1] land available for expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola		10,698		91,370
Botswana				-
Lesotho				-
Malawi		102		381
Mozambique	11	2,243	79	9,509
Namibia				-
South Africa	5	202	40	753
Swaziland				-
Tanzania	465	3,008	2,642	12,676
Zambia				-
Zimbabwe				-
Total	**481**	**16,253**	**2,581**	**114,689**

[1] includes moderately to very suitable land

TABLE 6.36

Oil palm (compact) production ('000 tons) in suitable[1] land available for intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola		352		3,769
Botswana		-		-
Lesotho		-		-
Malawi		98		365
Mozambique		474	3	1,780
Namibia		-		-
South Africa	38	276	259	1,029
Swaziland		-		-
Tanzania	2,395	9,249	11,599	37,942
Zambia		-		-
Zimbabwe		-		-
Total	**2,433**	**10,449**	**11,861**	**44,885**

[1] includes moderately to very suitable land

FIGURE 6.43

Potential land for oil palm (compact) expansion under tillage-based production at high level of inputs by suitability index

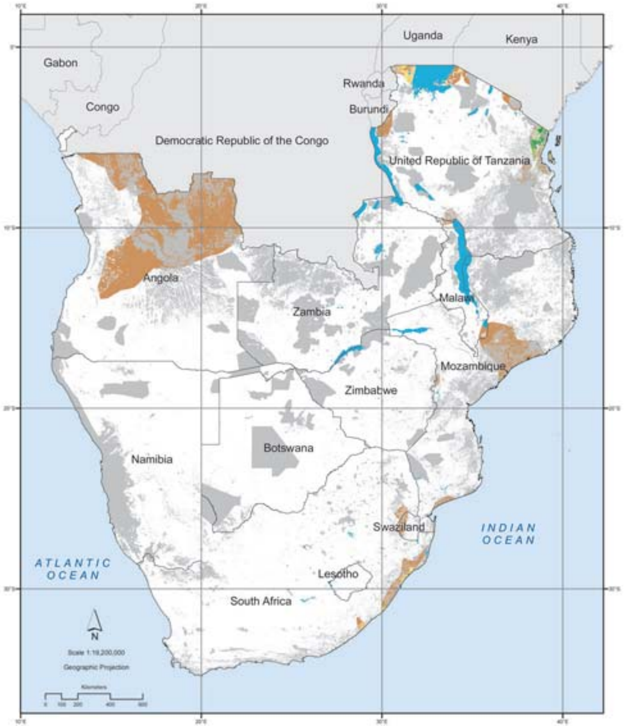
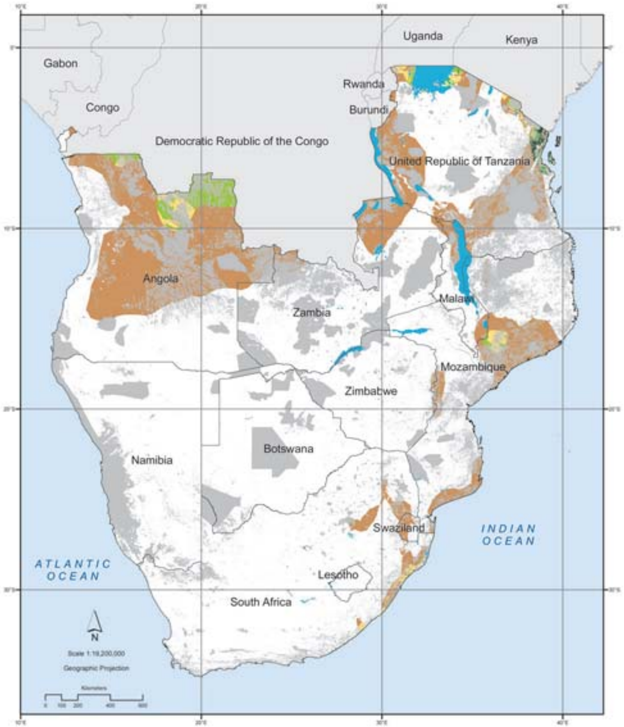


FIGURE 6.44

Potential land for oil palm (compact) expansion under Conservation Agriculture at high level of inputs by suitability index



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- ☐ Not Suitable
- ■ Excluded areas
- ■ Water bodies

6.2.2 Sunflower

The geographical distribution of the agro-climatic suitability of sunflower at low- and high-input level is shown for TA in Figure 6.45, and for CA in Figure 6.46. Under TA, 54.35 percent of the total regional land area is agro-climatically suitable for sunflower production, whereas under CA, 60.83 percent of the total regional land area is suitable (Table 6.37). As in the case of sweet sorghum, the bulk of agro-climatically suitable land is located in the northern part of the study region: Tanzania, Angola, Zambia, Malawi, Mozambique and Zimbabwe.

When soil and terrain (slope) constraints are applied to the agro-climatic suitability assessment, regional land suitability for sunflower drops to 32.45 percent under low inputs, and 36.69 percent under high inputs for TA (Table 6.38). For CA, regional land suitability drops to 43.13 percent under low inputs and to 45.6 percent under high inputs.

Regional distribution of the Land Suitability Index for sunflower at high- and low-input levels is shown in Figures 6.47 and 6.48 for TA and CA, respectively. These maps show the location of suitable land for sunflower cultivation within agro-climatically suitable zones for each country in the region.

Estimates of suitable land available for sunflower expansion are presented in Tables 6.39 and 6.41, and for sunflower intensification in Table 6.40 and 6.42. Figures 6.49 and 6.50 show the distribution of potentially suitable land area for expansion with high-input levels under TA and CA, respectively. At low-input levels, there are almost 120 million ha of suitable land for expansion under TA (corresponding to one billion tonnes of sunflower seeds) and around 160 million ha under CA (corresponding to 1.2 billion tonnes of sunflower seeds). Suitable land for expansion at high-input levels increases to 130 million ha under TA (corresponding to 1.4 billion tonnes) and around 170 million ha under CA (corresponding to 1.5 billion tonnes).

Also in case of intensification there are opportunities to improve sunflower production, even if they represent a quarter in terms of land and production.

Under the various LUTs, it can therefore be demonstrated that sunflower production is potentially very feasible in terms of availability of suitable land and yield. Expansion of sunflower could help to meet any biofuel demands, mostly in the countries indicated above, with low impact on food security.

FIGURE 6.45
Agro-climatic suitability for sunflower under tillage-based production at high and low level of inputs

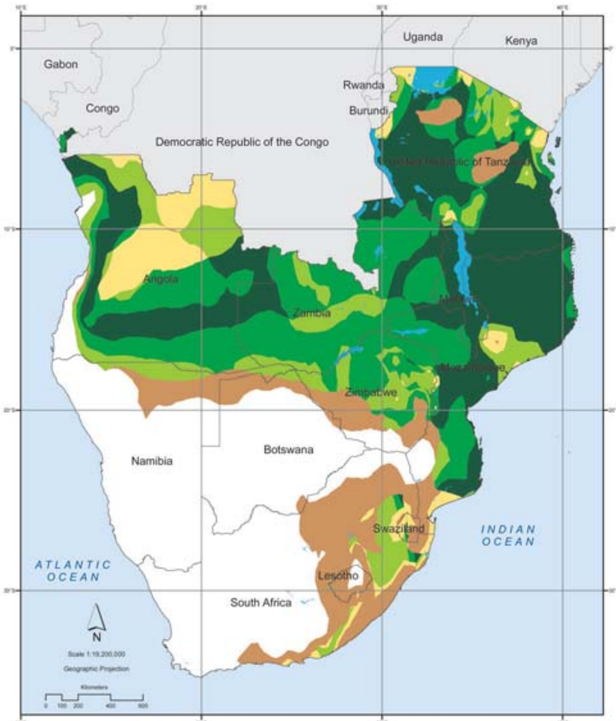
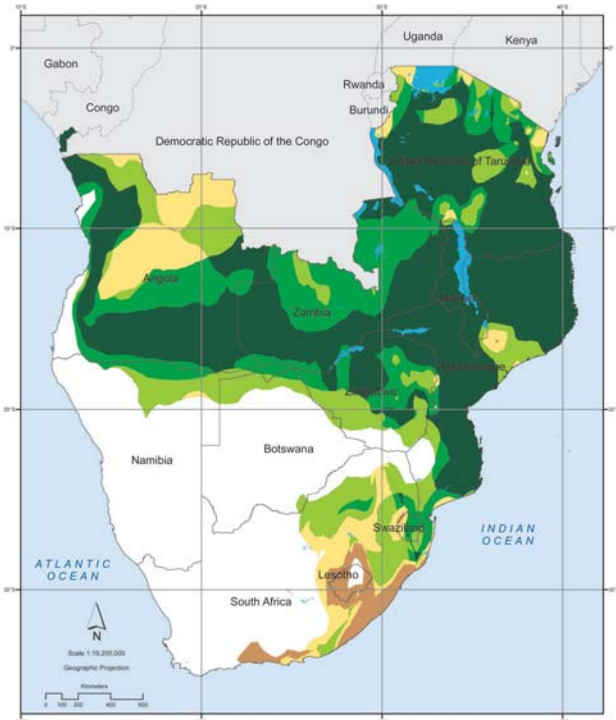


FIGURE 6.46
Agro-climatic suitability for sunflower under Conservation Agriculture at high and low level of inputs



Very Suitable (80-100%)	Suitable (60-80%)	Moderately Suitable (40-60%)	Marginally Suitable (20-40%)	Very Marginally Suitable (< 20%)	Not Suitable	Water bodies

TABLE 6.37

Percentage of agro-climatic suitable[1] land for sunflower

Country	Tillage-based production	Conservation Agriculture	Total Land Area '000 ha
	With low and high input	With low and high input	
Angola	74.57	75.01	124,945
Botswana	1.03	11.36	57,178
Lesotho	-	-	2,968
Malawi	99.40	99.40	9,483
Mozambique	89.91	93.33	77,636
Namibia	6.48	16.26	82,083
South Africa	8.60	18.14	120,067
Swaziland	58.93	72.48	1,637
Tanzania	89.58	95.81	88,107
Zambia	100.00	100.00	73,638
Zimbabwe	65.89	90.74	38,318
Total	**54.35**	**60.83**	**676,060**

[1] includes moderately to very suitable land

TABLE 6.38

Percentage of suitable[1] land for sunflower

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area '000 ha
	With low input		With high input		
Angola	36.66	49.61	38.71	50.34	124,945
Botswana	0.06	7.76	0.23	8.31	57,178
Lesotho	-	-	-	-	2,968
Malawi	94.44	99.29	94.47	99.30	9,483
Mozambique	52.07	63.24	55.26	64.05	77,636
Namibia	0.03	6.17	0.06	6.27	82,083
South Africa	2.34	9.99	4.39	12.34	120,067
Swaziland	5.43	34.53	22.65	39.10	1,637
Tanzania	45.16	65.30	64.26	73.70	88,107
Zambia	98.28	99.94	98.28	99.95	73,638
Zimbabwe	23.76	46.63	34.00	58.30	38,318
Total	**32.45**	**43.13**	**36.69**	**45.60**	**676,060**

[1] includes moderately to very suitable land

FIGURE 6.47
Land suitability index for sunflower under tillage-based production at high and low level of inputs

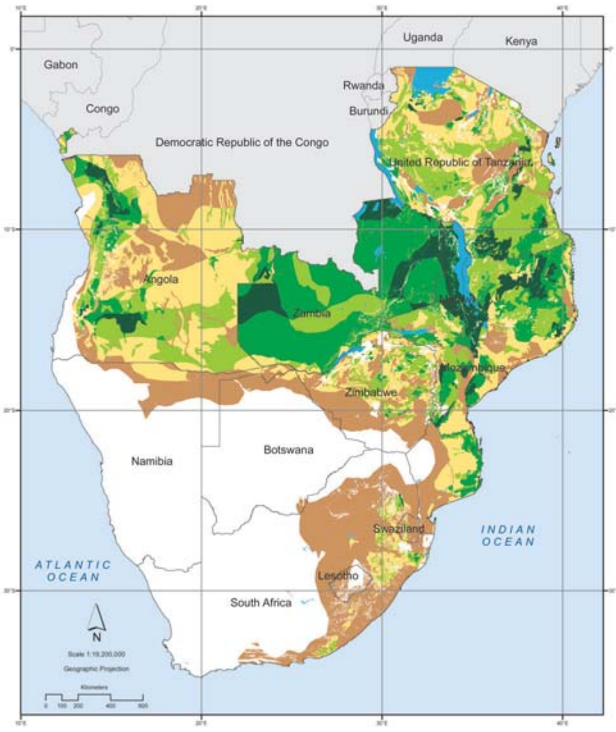
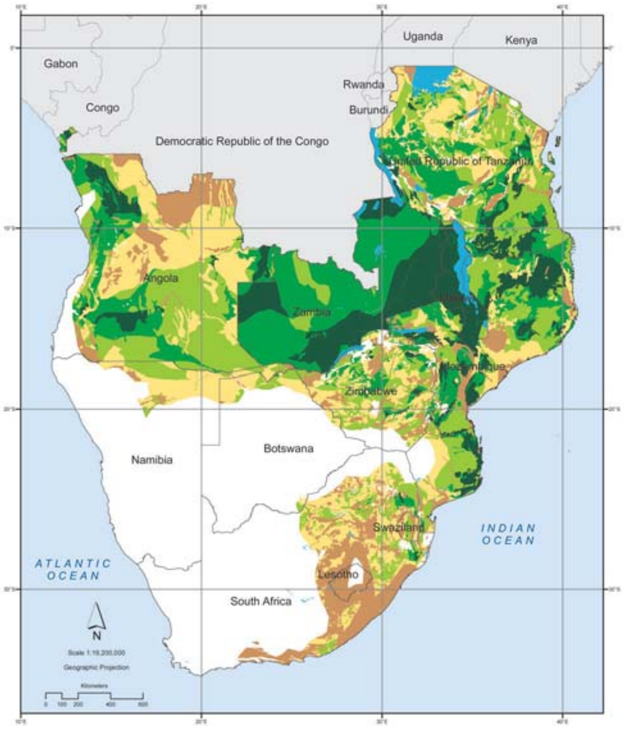


FIGURE 6.48
Land suitability index for sunflower under Conservation Agriculture at high and low level of inputs



■ Very Suitable (80-100%)
■ Suitable (60-80%)
■ Moderately Suitable (40-60%)
■ Marginally Suitable (20-40%)
■ Very Marginally Suitable (< 20%)
□ Not Suitable
■ Water bodies

TABLE 6.39

Percentage of suitable[1] land for sunflower expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area '000 ha
	With low input		With high input		
Angola	38.81	52.89	40.88	53.38	79,333
Botswana	0.04	5.90	0.19	6.49	36,581
Lesotho	-	-	-	-	2,300
Malawi	96.61	99.53	96.65	99.55	5,217
Mozambique	53.07	64.14	56.23	64.81	37,814
Namibia	0.03	5.68	0.07	5.78	61,560
South Africa	1.70	7.78	3.24	9.71	83,549
Swaziland	4.94	34.87	21.16	39.49	939
Tanzania	46.06	64.93	62.68	73.70	38,264
Zambia	98.91	99.93	98.91	99.94	40,313
Zimbabwe	25.36	47.33	36.54	60.58	21,787
Total	**29.54**	**39.09**	**32.77**	**41.25**	**407,657**

[1] includes moderately to very suitable land

TABLE 6.40

Percentage of suitable[1] land for sunflower intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture	Total Land Area '000 ha
	With low input		With high input		
Angola	49.61	66.83	53.31	68.48	9,074
Botswana	0.11	18.19	0.25	18.98	9,368
Lesotho	-	-	-	-	650
Malawi	95.29	99.05	95.30	99.06	2,142
Mozambique	49.96	63.30	55.29	64.02	12,409
Namibia	0.05	30.06	0.06	30.07	3,561
South Africa	3.47	16.07	7.24	20.09	21,856
Swaziland	9.61	38.57	27.97	41.78	311
Tanzania	38.65	57.63	57.92	69.71	18,612
Zambia	96.74	99.97	96.74	99.97	5,432
Zimbabwe	24.74	46.78	35.37	58.37	10,700
Total	**30.43**	**46.34**	**37.46**	**51.32**	**94,116**

[1] includes moderately to very suitable land

TABLE 6.41

Sunflower production ('000 tons) in suitable[1] land available for expansion

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	237,047	254,404	361,039	371,718
Botswana	72	351	11,671	13,119
Lesotho	-	-	-	-
Malawi	56,507	56,542	60,732	60,757
Mozambique	185,899	200,117	234,910	243,832
Namibia	93	206	22,938	23,383
South Africa	8,889	17,013	43,495	54,280
Swaziland	360	1,306	2,572	2,890
Tanzania	138,142	232,012	209,593	290,572
Zambia	349,951	349,970	379,187	379,205
Zimbabwe	39,803	56,043	77,241	100,051
Total	**1,016,763**	**1,167,964**	**1,403,378**	**1,539,807**

[1] includes moderately to very suitable land

TABLE 6.42

Sunflower production ('000 tons) in suitable[1] land available for intensification

Country	Tillage-based production	Conservation Agriculture	Tillage-based production	Conservation Agriculture
	With low input		With high input	
Angola	35,076	38,459	54,162	57,072
Botswana	53	121	9,222	9,701
Lesotho	-	-	-	-
Malawi	22,757	22,764	24,627	24,633
Mozambique	55,526	62,594	74,122	78,104
Namibia	9	11	7,208	7,212
South Africa	4,679	9,634	22,758	28,584
Swaziland	239	610	995	1,067
Tanzania	53,994	100,021	86,210	129,033
Zambia	46,390	46,391	54,525	54,526
Zimbabwe	19,182	26,822	38,569	48,768
Total	**237,905**	**307,427**	**372,398**	**438,700**

[1] includes moderately to very suitable land

FIGURE 6.49

Potential land for sunflower expansion under tillage-based production at high level of inputs by suitability index

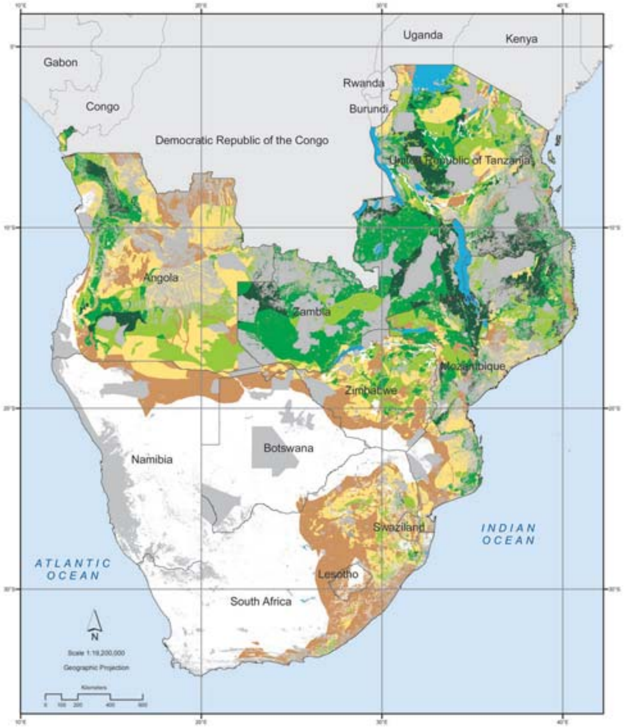
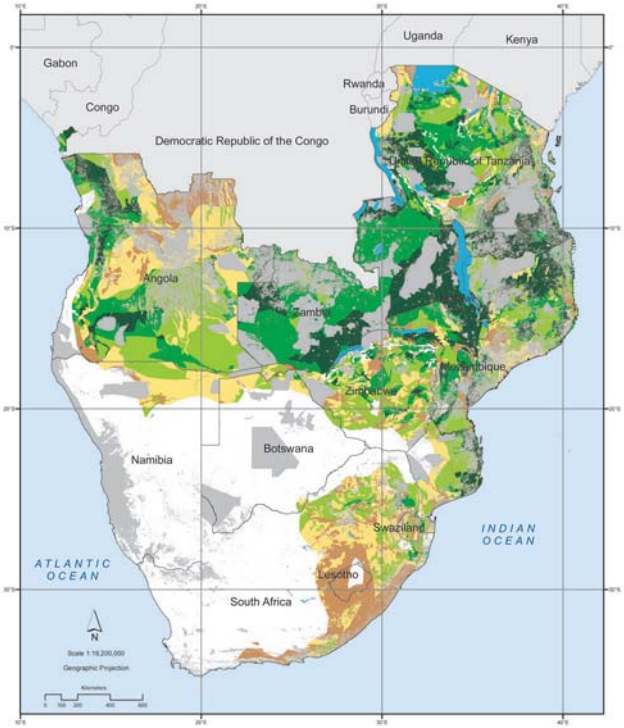


FIGURE 6.50

Potential land for sunflower expansion under Conservation Agriculture at high level of inputs by suitability index



- ■ Very Suitable (80-100%)
- ■ Suitable (60-80%)
- ■ Moderately Suitable (40-60%)
- ■ Marginally Suitable (20-40%)
- ■ Very Marginally Suitable (< 20%)
- □ Not Suitable
- ■ Excluded areas
- ■ Water bodies

6.3 CONCLUDING REMARKS

Access to energy is a prerequisite for sustainable development, in particular in the less-developed countries. Over the past few years, energy security has become a critical issue worldwide. There are basically two key dimensions of energy security:

- quantity, which is related to physical supply shortfalls that can occur between production and consumption of energy as a result of infrastructural inadequacy or failure;
- price, which is related to distortions caused by high prices and fluctuations in the price of energy products and services.

In Africa, affordability takes on a particular meaning. In many cases renewable energy could be a viable option for on/off grid rural electrification, industrial applications and energy security. The purpose of the analysis carried out in the Southern Africa region and presented in this publication was to assess potential land resources available for the production of bioenergy crops, by assessing crop and land suitability and, based on the results, estimating how much potential suitable land is available.

The results published here provide an assessment of the potential for each crop being considered as a bioenergy crop, and where it could best be produced under rainfed conditions. Moreover, the analysis shows how the land suitability for a specific crop in a specific area, and consequently the production of bioenergy crops, can be improved with a change in the agriculture management system (tillage-based vs. Conservation Agriculture) and through the application of inputs (low or high).

Most of the countries in the study region are both aware of and concerned about the potential trade-off between food, environment and feedstock production. Bioenergy developments must not compete with lands already being used, or which have been set aside, for food production and with specific environmental restrictions.

Overall, the assessment provides a technical indication that sweet sorghum for bioethanol production, and sunflower for biodiesel production, show relatively high potential at the regional level.

Lowland sweet sorghum is suitable in most of the countries of Southern Africa region, in particular in the northern areas, ranging from 160 to 205 million ha in all, depending on the suitable land for expansion and intensification under the different sweet sorghum LUTs. In Zambia, Malawi, Tanzania, Mozambique and Angola, potential suitable land for sweet sorghum is more than 50 percent of the total land available in each country for expansion and intensification.

The level of production inputs does not result in a noteworthy increase in the extent of the suitable land, but does result in a four-fold increase in potential production capacity. To mobilise such additional potential, cost analysis and affordability studies would need to be carried out, including research on accessibility to agricultural inputs which is one of the most limiting factors in agriculture for many African countries.

The production management system influences both the extent and yield of potential suitable land for lowland sweet sorghum because of both better agro-climatic and agro-edaphic suitability under CA. Thus, CA limits the decrease of suitable land to about 28 percent as opposed to 35 percent under TA, once the soil and landform constraints have been applied.

Highland sweet sorghum has a smaller suitable land area (from 45 to 90 million ha) compared to lowland sorghum, and is mostly concentrated in the highlands of Angola, Zambia, Tanzania and South Africa. Under CA, suitable land would be doubled compared to TA, principally because of the workability at high slopes.

Very similar conclusions of the ones related to sweet sorghum lowland can be drawn for sunflower in terms of location, extent and comparison between the two agriculture management and level of inputs.

Cassava, which is considered to be a staple food crop after maize in most of the countries in the Southern Africa region, has good potential as bioethanol feedstock in Angola, Tanzania and Mozambique, ranging from almost 20 million to 50 million ha under expansion (80 percent) and intensification (20 percent). If cassava were to be produced under a CA system rather than TA systems, more than twice the area of suitable land would become available. The input level would increase total production by five under TA and by four under CA. However, the absolute production levels would be two to three times greater under CA.

Sugarcane for bioethanol production and oil palm for biodiesel production have very limited potential under rainfed conditions for biofuel development at the regional level for both production systems and levels of inputs. For sugarcane, suitable land for potential expansion is concentrated in Northern Angola and in the Zambezi river basin in Mozambique, while in Tanzania suitable land is located in the coastal region in an area already under agricultural use. It may be possible to increase suitable land area by changing from a tillage-based agriculture system to a conservation agriculture management system, but the potential production levels would still be very low, which means that consideration in a strategic regional plan on bioenergy development would need further study. For oil palm, suitable land is very limited and mainly concentrated in the coastal region in Tanzania. Very localised opportunities could exist under irrigated conditions for both crops, but an assessment of water availability and requirements would need to be carried for various irrigated LUTs.

It is hoped that the methodology and the assessment described in this report will form a basis for further work at both regional and national level for planning and capacity development.

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Annex 1

Applications of the agro-ecological zones approach

Agro-ecological zones (AEZ) project began in FAO in 1976 to assess production potential of land resources in the developing world, and to provide the physical database necessary for planning future agriculture development (FAO, 1978-81). The FAO study developed the concept and methodology to characterize tracts of land by quantified information on climate, soil and other physical factors which are used to predict the agronomic suitability and potential yield of various crops according to their specific environmental, inputs and management needs. Climate, soil and terrain data were combined into a 1:5 million scale land resources database of several thousand unique agro-ecological cells. For each of these, crop requirements and crop growth models were applied to estimate agronomically attainable potential yields and outputs of rainfed crops for a range of input and management levels.

This made it possible for FAO to undertake, with support from the United Nations Population Fund (UNFPA), assessments of the potential population supporting capacities of developing nations (FAO, 1980). Subsequently, in collaboration with UNFPA and IIASA, FAO assessed the supporting capacities of 117 developing nations, grouped into five regions – Africa, Southwest Asia, Southeast Asia, Central America and South America (Higgins *et al.*, 1982). The methodology and the findings were discussed at the 1983 FAO Conference (FAO, 1984) which, recognising the importance of such work for development, recommended that future activities be concentrated at the national level. To do this, more refined methods had to be developed for use at the larger scales (less than 1:1 million scale) required for national and sub-national levels.

Since then, the AEZ methodology has been applied in national development planning activities in several countries including Mozambique (Kassam *et al*, 1982), Bangladesh (Brammer *et al*, 1988), and Kenya (Kassam *et al*, 1993). The AEZ methodology has also been promoted by national authorities in several countries in Asia including ASEAN member countries and China, and in Africa including SADC member countries, Ethiopia, Nigeria and Sierra Leone. More recently, AEZ approach is being applied in the BEFS project in Tanzania, Thailand and Peru (FAO, 2010).

The original AEZ database for the developing regions was expanded by FAO in collaboration with IIASA to include developed regions under the

Global AEZ (GAEZ) study (FAO/IIASA, 2002) at 1:5 million scale. The original AEZ database and the GAEZ database have been deployed in several global perspective studies such as Agriculture Towards 2000 series (e.g. FAO, 2003) to address regional and global issues such as food security, land and water resources availability, ecosystem degradation, climate change impact, and international research priorities.

The Southern Africa regional assessment presented in this report is the first attempt at 30 arc-second resolution (equivalent to almost one kilometre at the equator) and it is based on soil information at 1:2 million scale. In terms of implementation, the major difference compared with past AEZ studies is this assessment analyses and compares two types of production systems, the tillage-based system and Conservation Agriculture systems as defined by FAO (www.fao.org/ag/ca).

Annex 2

Sources of the land resources inventory

Figure	*Source of the map*
Figure 3.1	*FAO, 2006. New LocClim – the Local Climate Estimator.*
Figure 3.2	*FAO, 2006. New LocClim – the Local Climate Estimator, elaborated for the report FAO, 2012. Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region.*
Figure 3.3	*FAO, 2006. New LocClim – the Local Climate Estimator, elaborated for the report FAO, 2012. Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region.*
Figure 3.4	*FAO, 2006. New LocClim – the Local Climate Estimator, elaborated for the report FAO, 2012. Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region.*
Figure 3.7	*FAO, 2006. New LocClim – the Local Climate Estimator, elaborated for the report FAO, 2012. Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region.*
Figure 3.8	*FAO, 2008. Harmonized World Soil Database (HWSD).*
Figure 3.9	*FAO, 2008. Harmonized World Soil Database (HWSD).*
Figure 3.11	*National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). Shuttle Radar Topography Mission – Digital Elevation Model at 90-meter.*
Figure 5.1	*ESA, 2005-06. Globcover project, based on Envisat's Medium Resolution Imaging Spectrometer (MERIS) instrument.*
Figure 5.2	*UNEP-WCMC, 2009. World Database on Protected Areas.*
Figure 5.3	*University of Frankfurt and FAO, 2007. Global map of irrigation areas (version 4.0.1).*
Figure 5.4	*FAO, 2012. Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region.*
Figure 5.5	*FAO, 2012. Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region.*
Figure 5.6	*U.S. National Geospatial-Intelligence Agency. Vector Map Level 0 (VMap0).*
Figure 5.7	*FAO, 2008. Poverty Mapping Urban and Rural Population for the year 2005.*
Figure 5.8	*Demographic Health Survey, 2000-2010. Nutritional status survey.* *United Nation Children's Fund., 2000-2010. Multiple Indicator Cluster Surveys.* *World Health Organization, 2000-2010. Global Database on Child Growth and Malnutrition.*
From Figure 6.1 to Figure 6.50	*FAO, 2012. Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region.*

Annex 3

An example of soil suitability ratings for sunflower

SYM90	Description	TA-L	TA-H	CA-L	CA-H
ACf	Ferric Acrisols	S2	50%S1; 50%S2	S1	S1
ACg	Gleyic Acrisols	N	N	N	N
Ach	Haplic Acrisols	S2	50%S1; 50%S2	S1	S1
ACp	Plinthic Acrisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
ACu	Humic Acrisols	S2	50%S1; 50%S2	S1	S1
Alf	Ferric Alisols	S2	S1	S1	S1
ALg	Gleyic Alisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
ALh	Haplic Alisols	S2	S1	S1	S1
ALu	Humic Alisols	S2	S1	S1	S1
ANh	Haplic Andosols	S1	S1	S1	S1
ANm	Mollic Andosols	S1	S1	S1	S1
ANu	Umbric Andosols	S1	S1	S1	S1
ANz	Vitric Andosols	N	N	N	N
ARa	Albic Arenosols	N	N	N	N
ARb	Cambic Arenosols	S2	S2	S1	S1
ARc	Calcaric Arenosols	S2	S2	S1	S1
ARg	Gleyic Arenosols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
ARh	Haplic Arenosols	S2	S2	S1	S1
ARl	Luvic Arenosols	S2	S2	S1	S1
ARo	Ferralic Arenosols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
ATa	Aric Anthrosols	N	N	N	N
CHk	Calcic Chernozems	S2	S2	S1	S1
CHl	Luvic Chernozems	S2	S2	S1	S1
CLh	Haplic Calcisols	S2	S2	S1	S1
CLl	Luvic Calcisols	S2	S2	S1	S1
CLp	Petric Calcisols	S2	S2	S1	S1
CMc	Calcaric Cambisols	S1	S1	S1	S1
CMd	Dystric Cambisols	S2	50%S1; 50%S2	S1	S1
CMe	Eutric Cambisols	S1	S1	S1	S1
CMg	Gleyic Cambisols	S1	S1	S1	S1
CMi	Gelic Cambisols	N	N	N	N
CMo	Ferralic Cambisols	50%S2; 50%N	50%S1; 50%S2	50%S1; 50%N	S1
CMu	Humic Cambisols	S1	S1	S1	S1
CMv	Vertic Cambisols	50%S1; 50%S2	S1	S1	S1
CMx	Chromic Cambisols	S1	S1	S1	S1
FLc	Calcaric Fluvisols	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N
FLd	Dystric Fluvisols	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N
FLe	Eutric Fluvisols	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N
FLm	Mollic Fluvisols	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N

SYM90	Description	TA-L	TA-H	CA-L	CA-H
FLs	Salic Fluviosls	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N
FLt	Thionic Fluvisols	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N
FLu	Umbric Fluvisols	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N	20%S1; 80%N
FRg	Geric Ferralsols	S2	S2	S1	S1
FRh	Haplic Ferralsols	50%S1; 50%S2	50%S1; 50%S2	S1	S1
FRp	Plinthic Ferralsols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
FRr	Rhodic Ferralsols	S1	S1	S1	S1
FRu	Humic Ferralsols	S2	50%S1; 50%S2	S1	50%S1; 50%N
FRx	Xanthic Ferralsols	S2	S2	S1	S1
GLd	Dystric Gleysols	N	N	N	N
GLe	Eutric Gleysols	N	N	N	N
GLi	Gelic Gleysols	N	N	N	N
GLk	Calcic Gleysols	N	N	N	N
GLm	Mollic Gleysols	N	N	N	N
GLu	Umbric Gleysols	N	N	N	N
GRh	Haplic Greyzems	S1	S1	S1	S1
GYh	Haplic Gypsisols	S1	S1	S1	S1
GYk	Calcic Gypsisols	S1	S1	S1	S1
GYl	Luvic Gypsisols	S1	S1	S1	S1
GYp	Petric Gypsisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
HSf	Fibric Histosols	N	N	N	N
HSs	Terric Histosols	N	N	N	N
KSh	Haplic Kastanozems	S2	S2	S1	S1
KSk	Calcic Kastanozems	S2	S2	S1	S1
KSl	Luvic Kastanozems	50%S1; 50%S2	50%S1; 50%S2	S1	S1
LPd	Dystric Leptosols	N	N	N	N
LPe	Eutric Leptosols	N	N	N	N
LPi	Gelic Leptosols	N	N	N	N
LPk	Rendzic Leptosols	N	N	N	N
LPm	Mollic Leptosols	N	N	N	N
LPq	Lithic Leptosols	N	N	N	N
LPu	Umbric Leptosols	N	N	N	N
LVa	Albic Luvsiols	N	N	N	N
LVf	Ferric Luvisols	50%S2; 50%N	50%S1; 50%S2	50%S1; 50%N	S1
LVg	Gleyic Luvisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
LVh	Haplic Luvisols	S1	S1	S1	S1
LVj	Stagnic Luvisols	N	N	N	N
LVk	Calcic Luvisols	S2	S1	S1	S1
LVv	Vertic Luvisols	S2	50%S1; 50%S2	S1	S1
LVx	Chromic Luvisols	S1	S1	S1	S1
LXf	Ferric Lixisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
LXg	Gleyic Lixisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
LXh	Haplic Lixisols	S1	S1	S1	S1
LXp	Plinthic Lixisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
NI	Nonsoil	N	N	N	N
NI	Nonsoil	N	N	N	N
NTh	Haplic Nitisols	S1	S1	S1	S1
NTr	Rhodic Nitisols	S1	S1	S1	S1

SYM90	Description	TA-L	TA-H	CA-L	CA-H
NTu	Humic Nitisols	S1	S1	S1	S1
PHc	Calcaric Phaeozems	S2	S2	S1	S1
PHg	Gleyic Phaeozems	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
PHh	Haplic Phaeozems	S1	S1	S1	S1
PHj	Stagnic Phaeozems	N	N	N	N
PHl	Luvic Phaeozems	S1	S1	S1	S1
PLd	Dystric Planosols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N
PLe	Eutric Planosols	S2	S2	S1	S1
PLu	Umbric Planosols	S2	S2	S1	S1
PTa	Albic Plinthosols	N	N	N	N
PTe	Eutric Plinthosols	N	N	N	N
PZc	Carbic Podzols	N	N	N	N
PZg	Gleyic Podzols	N	N	N	N
PZh	Haplic Podzols	N	N	N	N
RGc	Calcaric Regosols	S2	S2	S1	S1
RGd	Dystric Regosols	S2	S1	S1	S1
RGe	Eutric Regosols	S1	S1	S1	S1
RGu	Umbric Regosols	S1	S1	S1	S1
RK	Rock outcrops	N	N	N	N
SCg	Gleyic Solonchaks	N	N	N	N
SCh	Haplic Solonchaks	N	N	N	N
SCk	Calcic Solonchaks	N	N	N	N
SCn	Sodic Solonchaks	N	N	N	N
SNg	Gleyic Solonetz	N	N	N	N
SNh	Haplic Solonetz	N	N	N	N
SNj	Stagnic Solonetz	N	N	N	N
SNk	Calcic Solonetz	N	N	N	N
SNm	Mollic Solonetz	N	N	N	N
VRe	Eutric Vertisols	50%S2; 50%N	S1	50%S1; 50%N	S1
VRk	Calcic Vertisols	50%S2; 50%N	S1	50%S1; 50%N	S1
VRy	Gypsic Vertisols	50%S2; 50%N	50%S2; 50%N	50%S1; 50%N	50%S1; 50%N

Annex 4

Land suitability assessment software

The Land Suitability Assessment (LSA) software was initially developed under the BEFS project. The main objective was providing an easy tool to the BEFS partner countries to perform and improve with local expertise the LSA analysis carried out by the BEFS Team. Even if under the BEFS project the tool focused on the assessment of bioenergy crops, the LSA software can perform the analysis for all agricultural crops.

FIGURE A.1
LSA interface

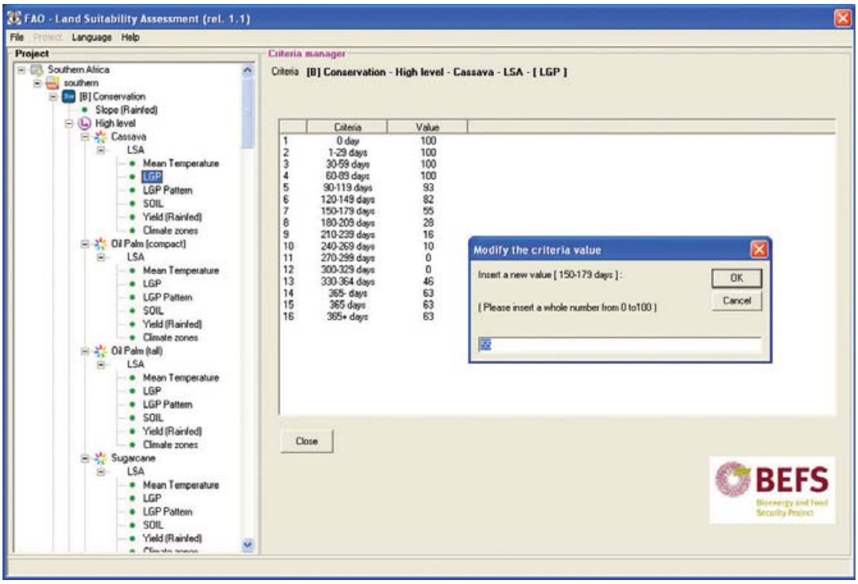
The software has a user-friendly interface that guides the user in the implementation of the assessment from the required minimum data inputs i.e., GIS data raster and criteria or suitability ratings, to the production of the results in map and tabular format.

LSA can perform the analysis at different levels (sub-national, country, region and continent) and three different raster resolutions (3 arc-second, 30 arc-second and 5 arc-minute). It does not generate the GIS input data that should be done in Grid-ESRI format: the data are imported in few and rapid steps.

By default the software uses two basic FAO databases: the Global Administrative Unit Level (GAUL) for the first and second administrative boundaries level and the Harmonized World Soil Database (HWSD) for the soil information. It is also possible to import more detailed data related to country boundaries and soil information using the function "Custom".

The suitability criteria could be quickly imported and exported from specific Excel form (LSA criteria form) or inserted/modified directly into specific masks, as shown in Figure A.2.

FIGURE A.2
Criteria manager mask



Criteria [B] Conservation - High level - Cassava - LSA - [LGP]

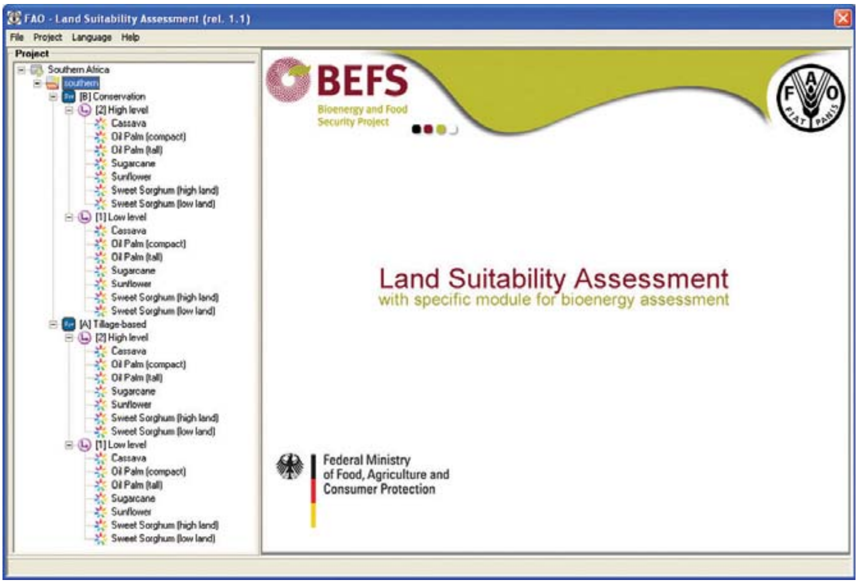
	Criteria	Value
1	0 day	100
2	1-29 days	100
3	30-59 days	100
4	60-89 days	100
5	90-119 days	93
6	120-149 days	82
7	150-179 days	55
8	180-209 days	28
9	210-239 days	16
10	240-269 days	10
11	270-299 days	0
12	300-329 days	0
13	330-364 days	46
14	365- days	63
15	365 days	63
16	365+ days	63

Insert a new value [150-179 days] :

[Please insert a whole number from 0 to100]

For each study area (country, region, etc.) the assessment is organized in *Project*, which contains the settings decided by the user e.g., administrative level of the tabular results and resolution of GIS analysis. In each project the user can include a different number of LUTs – namely combinations of crop, production system and input level – according to the research needs. Figure A.3 shows the structure of the Southern Africa project, including seven crops (and crop varieties), two production systems and two input levels.

FIGURE A.3
Southern Africa project



LSA produces information on agro-climatic and land suitable area and potential production for each LUT by administrative level - according to the project settings - in tabular format. In raster format the results are the following:

- Agro-climatic suitability map for each crop, production system and input level;
- Land Suitability Index map for each crop, production system and input level;
- Potential production map for each crop, production system and input level;

The software's interface and commands are available in four languages: English, Spanish, French and Italian.

The installation is completely guided by setup wizard. The minimum system requirements are provided in Table A.1.

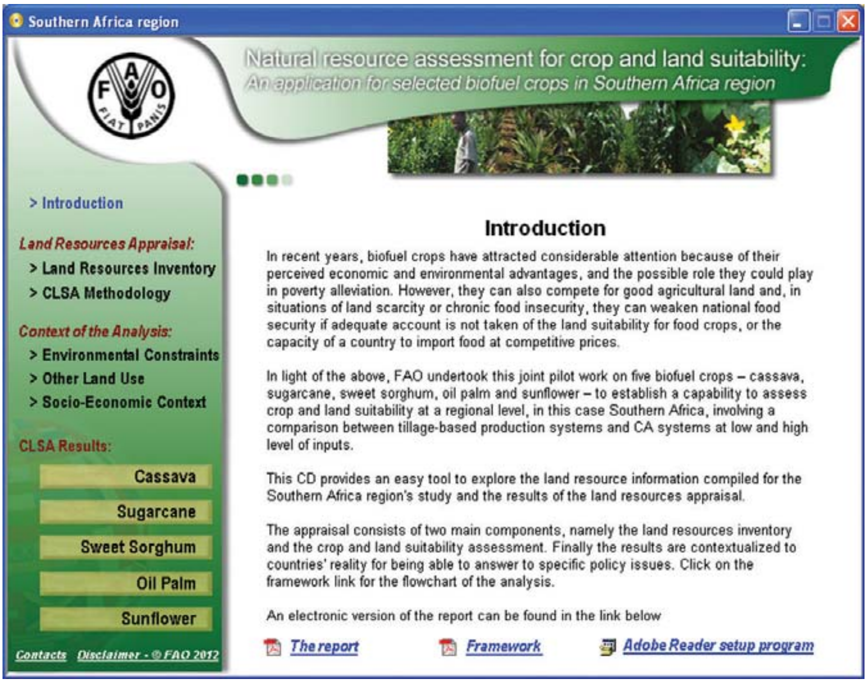
TABLE A.1
Minimum system requirements

Hardware	Software
Processor: Pentium 800 Mhz minimum	ArcGIS ESRI Desktop 9.2
Operating system: Microsoft Window 2000/XP/Vista	ArcGIS ESRI Workstation 9.2
RAM: 256 MByte minimum	ArcGIS ESRI Spatial Analyst Extension
Disk Space: 1 GByte	Microsoft Excel
	Microsoft Access (optional)
	Acrobat Reader

Annex 5
CD Results

This report includes a CD that contains a description of the land resources inventory and the results of the crop and land suitability assessment for Southern Africa region. The data are accessible through a user-friendly interface that drives the reader in the three main components of the analysis: the Land Resources Appraisal, the Context of the Analysis and the Crop and Land Suitability Results.

FIGURE A.4
Introduction page



Introduction

In recent years, biofuel crops have attracted considerable attention because of their perceived economic and environmental advantages, and the possible role they could play in poverty alleviation. However, they can also compete for good agricultural land and, in situations of land scarcity or chronic food insecurity, they can weaken national food security if adequate account is not taken of the land suitability for food crops, or the capacity of a country to import food at competitive prices.

In light of the above, FAO undertook this joint pilot work on five biofuel crops – cassava, sugarcane, sweet sorghum, oil palm and sunflower – to establish a capability to assess crop and land suitability at a regional level, in this case Southern Africa, involving a comparison between tillage-based production systems and CA systems at low and high level of inputs.

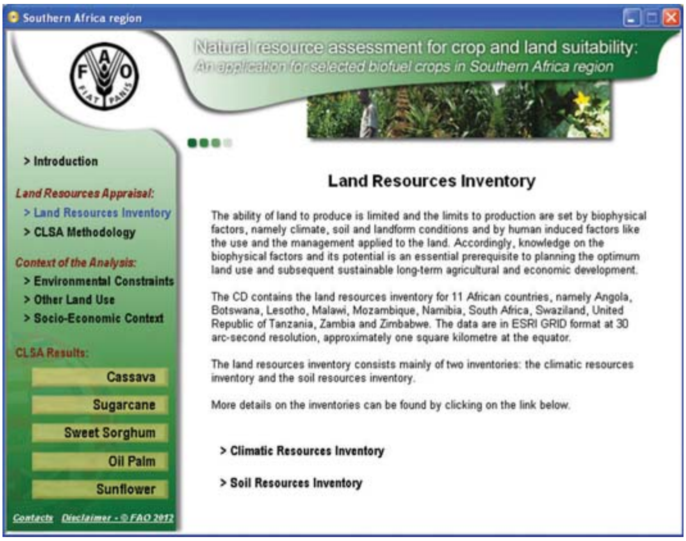
This CD provides an easy tool to explore the land resource information compiled for the Southern Africa region's study and the results of the land resources appraisal.

The appraisal consists of two main components, namely the land resources inventory and the crop and land suitability assessment. Finally the results are contextualized to countries' reality for being able to answer to specific policy issues. Click on the framework link for the flowchart of the analysis.

An electronic version of the report can be found in the link below

The Land Resources Appraisal section contains the Land Resources Inventory (Climatic and Soil Resources Inventory) and a description of the methodology of the Crop and Land Suitability Assessment (CLSA).

FIGURE A.5
Land Resources Inventory page



Land Resources Inventory

The ability of land to produce is limited and the limits to production are set by biophysical factors, namely climate, soil and landform conditions and by human induced factors like the use and the management applied to the land. Accordingly, knowledge on the biophysical factors and its potential is an essential prerequisite to planning the optimum land use and subsequent sustainable long-term agricultural and economic development.

The CD contains the land resources inventory for 11 African countries, namely Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe. The data are in ESRI GRID format at 30 arc-second resolution, approximately one square kilometre at the equator.

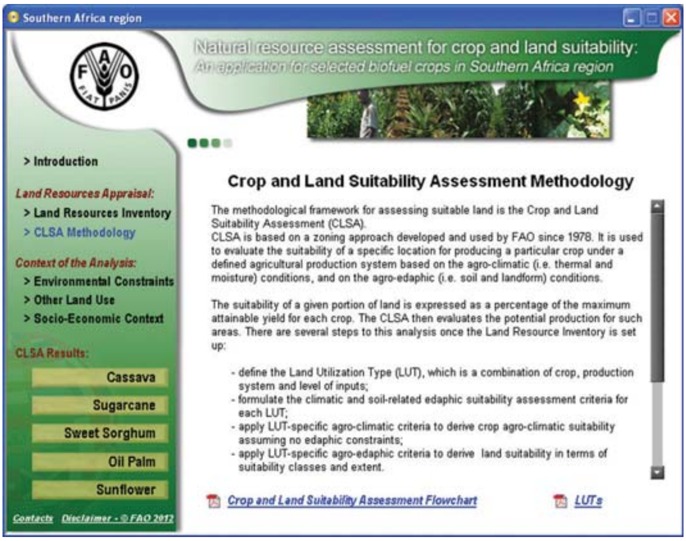
The land resources inventory consists mainly of two inventories: the climatic resources inventory and the soil resources inventory.

More details on the inventories can be found by clicking on the link below.

> Climatic Resources Inventory

> Soil Resources Inventory

FIGURE A.6
Methodology page



Crop and Land Suitability Assessment Methodology

The methodological framework for assessing suitable land is the Crop and Land Suitability Assessment (CLSA).
CLSA is based on a zoning approach developed and used by FAO since 1978. It is used to evaluate the suitability of a specific location for producing a particular crop under a defined agricultural production system based on the agro-climatic (i.e. thermal and moisture) conditions, and on the agro-edaphic (i.e. soil and landform) conditions.

The suitability of a given portion of land is expressed as a percentage of the maximum attainable yield for each crop. The CLSA then evaluates the potential production for such areas. There are several steps to this analysis once the Land Resource Inventory is set up:

- define the Land Utilization Type (LUT), which is a combination of crop, production system and level of inputs;
- formulate the climatic and soil-related edaphic suitability assessment criteria for each LUT;
- apply LUT-specific agro-climatic criteria to derive crop agro-climatic suitability assuming no edaphic constraints;
- apply LUT-specific agro-edaphic criteria to derive land suitability in terms of suitability classes and extent.

Crop and Land Suitability Assessment Flowchart

LUTs

The Context of the Analysis section includes information on environmental constraints, other land use and socio-economic factors that should be taken into account in designing policy advice for bioenergy development.

FIGURE A.7
The context of the analysis page

Environmental Constraints

The assumption of the Crop and Land Suitability Assessment is that all land is available. The reality is quite different and in order to use the land assessment as the instrument to provide information for agricultural planning and development, an accurate evaluation of land use, environmental constraints and restrictions by law is required.

First of all protected areas and forests should be excluded as potential land that could be used for bioenergy crop production.

The protected areas were extracted from the World Database on Protected Areas

Other Land Use

The assumption of the Crop and Land Suitability Assessment is that all land is available. The reality is quite different and in order to use the land assessment as the instrument to provide information for agricultural planning and development, an accurate evaluation of land use, environmental constraints and restrictions by law is required. In this specific research a particular attention was given to areas already devoted to agriculture.
The potential competition between food and feedstock production is addressed in two ways:
- Looking at suitable land available for agriculture expansion
- Focusing on potential suitable land for agriculture intensification

Socio-economic context

Data on infrastructure, population and malnutrition could help to design more solid policy recommendations on crop promotion and land use planning with an orientation to rural development and poverty reduction.

The infrastructure development is one of the main limiting factors for the expansion of new industries. Most of agriculture areas in Africa continue to be adversely affected by lack of access to competitive markets due to high transport and transaction costs.

The potential productivity should be evaluated first of all in comparison to the number of people living in the specific area and how much food and energy they will require. More in general an expansion of a new sector like the bioenergy will require human resource in the overall life cycle: more people, mostly leaving in rural areas, working in agriculture for increasing the production of feedstock; unskilled and skilled human capital for the conversion of feedstock into bioenergy.

The CLSA Results section helps the reader to navigate and visualise the considerable amount of results of the assessment. By selecting the crop of interest, the reader accesses the results in map format: for each combination of production system and level of input, the agro-climatic suitability map and the land suitability index map can be found. These maps can be visualised without any exclusion areas or over-imposing environmental constraints or environmental constraints plus agricultural areas, looking at areas with potential expansion for agriculture.

FIGURE A.8
Map results

Sweet Sorghum (Lowland) maps

Show maps with:
● No excluded areas
○ Environment excluded areas
○ Agriculture excluded areas

Crop variety:
● Lowland
○ Highland

By clicking on the button at the bottom-right corner, the reader gets into the tabular results. The tables present all suitable and available area and potential production at country level and at first administrative level.

FIGURE A.9
Tabular results

Sweet Sorghum (Highland) tables

Show data-tables at :
● Country level
○ 1st administrative level

Details of calculation with:
● No exclusion areas
○ Environment exclusion areas
○ Agriculture exclusion areas
○ Agriculture intensification areas

Crop variety:
● Highland
○ Lowland

Natural Resource Assessment for Crop and Land Suitability: *An application for selected bioenergy crops in Southern Africa region*

The pilot regional assessment carried out for Southern Africa and described in this publication was designed to help evaluate the crop and land suitability of bioenergy crops which are also food crops, namely: cassava, sugarcane, sweet sorghum, sunflower and oil palm under rainfed production conditions. By providing critical bioenergy crop adaptability and land resources information, along with extensive maps, to policy-planners and decision-makers for socioeconomic development, it is expected that national policy and development capacity will also be strengthened.

The crop and land suitability assessments provide an up-to-date GIS database for climate, soil, terrain and vegetation information, and includes critical data sets, methodological and analytical support and the integration of FAO's AEZ methodology, including an inventory of land resources and specific ecological and agronomic adaptability requirements for selected bioenergy crops under the tillage-based production systems and under Conservation Agriculture.

The assessment also enhances and expands the current ECOCROP database and its applications by adding more detailed information on bioenergy crops and using a mapping function to enable countries to better plan and decide on their agricultural strategy with respect to food and bioenergy crops.

This publication seeks to assist government and institutional policy-planners and decision-makers in identifying places where energy crops could be grown and in understanding the geographic (agro-ecological and economic) context of bioenergy supplies, at country and regional levels. It will not only increase awareness about the environmental challenges related to the production systems of bioenergy crops, but will also contribute to the development of new production practices and technologies for sustainable agricultural intensification and diversification in the context of the new FAO "Save and Grow" paradigm.

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