Cranfield University

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The Application of Land Evaluation Technique in the north-east of Libya

Faculty of Environment

PhD Thesis

Cranfield University at Silsoe

Faculty of Environment

National Soil Resources Institute

PhD

2005

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The Application of Land Evaluation Technique in the north-east of Libya

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This thesis is submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy

"I dedicate this thesis to my wife Amal , whose patience and understanding long ago passed my understanding."

BASHIR NWER
2005

Abstract

Land evaluation is a prerequisite to achieving optimum utilisation of available land resources for agricultural production. The principal purpose of land evaluation is to predict the potential and the limitations of land for changing use. Food security is one of the most important issues of agriculture policy in Libya. The country aims to obtain self-sufficiency for its in agricultural products which contribute largely to the diet of most of the population. Therefore, eighty per cent of water transferred from aquifer-sourced in the south of the country to the north, is planned for agriculture development. Cereal crops such wheat, barley, maize and sorghum are given the highest priority. There is, therefore, a pressing need to develop an optimal land evaluation method to identify in which part of a region these selected crops could be grown favourably. The model should be developed in accordance with the priorities of the Libyan Government in developing a practical and applicable land evaluation system that can be used by the average computer user.

The FAO Framework was selected to conduct the land suitability assessment. This selection was based upon extensive and critical review of land evaluation methodologies and an evaluation of the objectives for and of the data available for study area. The FAO framework is a set of guidelines rather than a classification system, and model used builds upon this.

Fifteen land characteristics and their threshold values were determined and brought together in four land qualities. The land characteristics selected included: mean temperature in the growing season; rootable depth; soil texture; available water holding capacity; soil salinity; soil alkalinity; soil reaction; cation exchange capacity; organic matter; calcium carbonate; infiltration rate; soil drainage class, gravel and stones; soil erosion and steepness of slope.

Soil data and maps, climate data and topography data were obtained and assessed for the study area in order to create a land information system. A land information system was implemented. The land suitability model was constructed using Geographic Information System (GIS) capabilities and modelling functions. Soil, climate, erosion hazard, and slope were integrated in the GIS environment as information layers and then overlaid to produce as overall land suitability for each crop.

The results revealed that the study area has a good potential to produce the selected crops under irrigation provided that water and drainage requirement are met. Nearly 47 % of the study area is highly suitable for barley and 34 % of the study area is suitable for wheat production. In addition, 48 % of the study area is highly suitable for maize production and 70 % of is highly suitable for sorghum production.

The model specifications were assessed through verification, validation, and sensitivity analysis. The findings of the sensitivity analysis emphasised that soil and climate represented the most important factors in the study area. Conversely, slope and erosion were found to be less significant in the study area. The findings revealed a number of particularly highly sensitive characteristics which influence the results strongly. These land characteristics are: temperature, rootable depth, available water holding capacity, infiltration rate, hydraulic conductivity, soil reaction, soil salinity, cation exchange capacity, and organic matter.

The outputs of sensitivity analysis were used to guide the decision to establish trial plots of the selected crops for the purpose of further validation. In addition, there is a need for field tests which can be used to 'ground truth' the model. This approach was important as limitations in the data available could have affected the accuracy of the results.

Acknowledgements

I am most thankful to Almighty Allah for giving me the patience and making it possible for me to produce this work. I am grateful to many people for help, both direct and indirect with the research.

I would like to thank my supervisors Dr Stephen Hallett and Mr Tim Brewer for the encouragement and guidance they have given me in all aspects of this research. Dr Stephen Hallett has been an excellent mentor, and also provided much needed support, encouragement, and advice. I shall always remember all the phrases and words learnt throughout the meetings. It has been an enjoyable education experience. Mr Tim Brewer has played a vital role and has provided great encouragement and support. His detailed and precise comments were a motivation to progress in this thesis.

My Acknowledgements extended to Professor Peter Leeds Harrison (chairman of thesis committee) and Dr. Tim Hess (member of thesis committee) for their advice and support throughout the period of the research.

A special thank to Dr Ian Baillie for the interesting discussion and advice on the early and last stages of the research. I would like to thank Mrs Elizabeth Hallett for reading my thesis and her valuable comments. I would like to thank Dr Khaled Ben Mahmoud and Dr Ezzeddin Rhoma for their comments and encouragements. Dr Khaled has been the main provider of data and information about the study area. Therefore, he deserves a special thank you.

The Libyan High Education and Al Fateh University are acknowledged for providing me with a grant to carry out this research.

I am grateful to my wife Amal, my daughter Heba and my brother Nooraldean for their encouragement, understanding, and tolerance during the course of the study.

Special gratitude is due to Frank Verheijen and Sorche O'Keefe, for their company in the office. The smell of the double espresso and the sound of music in the office will never leave my mind. I thank them for extend my knowledge of western music and I will never forget this phrase “music education for Bash”. I would like also to thank Isabelle Beaudin who shared the office with me in the first year of this research. I am grateful to my NSRI colleagues who made me feel home and are one of the friendliest people I have come across.
Finally, many thanks to Fauzi Abukhriss, Khalif Hussein, Ishmael Alzean and Ali Almjhod for their support through the period of the study.

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1
Introduction

This Chapter illustrates the research problem and question. It also introduces the aims and objectives of the research.

1-1 Research Problem

The great challenge for the coming decades will be the task of increasing food production to ensure food security for the steadily growing world population, particularly in countries with limited water and land resources.

Food security is one of the most important issues of agricultural policy in Libya. The country aims to be self-sufficient in the main agricultural food products which contribute largely to the diet of most of the country's population. Hence, a project is underway to pump water from the south of the country to the north coast. Eighty per cent of the output water is planned for agricultural development. Production of cereal crops such as wheat, barley, maize and sorghum, are given the highest priority (GMRP, 1990).

Consequently, there is a pressing need to develop an optimal land evaluation method to identify in which part of a region selected crops could be grown successfully. A series of questions can be developed to investigate this need further, such as:

- which land evaluation methodology suits the Libyan environment?

- which criteria are appropriate to the Libyan environmental conditions taking into account the available data?
- which tool is appropriate for the application of this land evaluation methodology?

Effective land evaluation is a prerequisite to achieving optimum utilisation of available land resources for agricultural production. The principal purpose of land evaluation is to predict the potential and limitations of land for changing use. Land evaluation is the process of predicting land performance over time according to specific types of use. These predictions are then used to guide strategic land use decision making (Rossiter, 1996; Van Diepen et al., 1991).

Several land evaluation methods, concepts, and analytical procedures have been developed since 1950. The focus of these evaluations has shifted from broad to specific assessments. This has led to a diversity of approaches, ranging from straightforward soil survey interpretations to more sophisticated, multidisciplinary, integrated, regional studies, and to the application of simulation techniques (Van Diepen et al., 1991).

Some methods value the degree of suitability of resource properties, while others place more emphasis upon the possible limiting factors imposed by environmental conditions. Qualitative criteria are used in some methods while others are more quantitative. Some systems group land into a series of levels of importance (order, class, subclass…etc.). Other systems use mathematical formulae so that final results are expressed in numerical terms.

Land evaluation schemes are based on the local conditions and the level of data available for locations where they have been developed. Consequently, the land evaluation criteria and their associated threshold values are intended solely for those locations. Therefore, these land evaluation methods may not perform adequately in different environments. However, some of these methods can be described as a framework for land evaluation, such as the FAO method for land suitability.

A number of technological developments have facilitated the implementation of land evaluation principles. One of the most significant developments has been the incorporation of Geographic Information Systems (GIS). GIS facilitates the storage and analysis of a wide range of spatial data, and is used as a tool for land evaluation throughout the world. With GIS, the analysis of alternative scenarios can be produced as maps. This graphical presentation capability allows ready communication of the outcome in formats useful for guiding decision making at various administrative or technical levels.

Depending on the questions that need to be answered, land evaluation can be conducted at different scales (e.g. local, national, regional and even global) and with different levels of quantification (i.e. qualitative vs quantitative). Studies at the national scale may be useful in setting national priorities for development, whereas those targeted at the local level are useful for selecting specific projects for implementation.

In the light of these needs, possibilities and limitations, this research project will develop a land evaluation model for selected food crops in Libya. The Benghazi region to the east of the country has been selected as a study area, and aims to show how a land suitability model can be developed and applied to assist regional planners in other arid and semi-arid regions.

1-2 Research Aims and objectives

The aim of the research is "**to develop land evaluation for predicting the physical suitability of land for selected crops under irrigation in the North-eastern region of Libya".**

The individual research objectives are to:

1. Critically assess land evaluation methodologies and select /adapt a suitable methodology to suit the Libyan agricultural policy requirements and the use of soil resources;
2. Appraise the existing information available for north-east Libya including soil, and crop; management and climatic information for the region, and review and select data appropriate to the selected land evaluation method;
3. Develop a land suitability assessment for the key crops of irrigated wheat, barley, maize and sorghum in the North-eastern region of the country, where the irrigation scheme will be applied;
4. Critically evaluate parameters which will be used in the assessment (land characteristics) and undertake a sensitivity analysis for these parameters whereby both the variation of the thresholds adopted for each land characteristic, and also the variation of the weighting of each land characteristic are undertaken;
5. Develop a prototype framework for land evaluation in Libya to produce a physical land suitability evaluation.

2
Research Context

This Chapter introduces the general environmental context and institutional environment in Libya.

2-1 Introduction

Libya is located in the north of Africa and covers 1,759,540 million Km^2 (Figure 2-1). Only 4 per cent of the country is arable land, with the rest comprising rocky outcrops and loose surface materials. In addition, there is a shortage of land receiving sufficient rainfall for agriculture. The highest rainfall occurs in the northern Tripoli region (Jabal Nafusah and Jifarah Plain) and in the northern Benghazi region (Jabal al Akhdar). These two areas are the only regions where the average yearly rainfall exceeds the minimum (250-300 mm) considered necessary to sustain rain-fed agriculture (Figure 2.1). Rainfall occurs during the winter months and shows extreme variability from year to year and from place to place (Pallas, 1980).

As a result of the low precipitation, groundwater resources have been used in the development of agriculture in Libya. The expanding economy and growing population along the coastal strip is creating an increasing demand on groundwater resources. Hence, the traditional groundwater resources are become increasingly at risk through intensive use, which in turn is resulting in saline intrusion into the coastal aquifer. Pallas (1980) and Elasswad (1995) state that the groundwater on the coastal regions is over exploited and non-sustainable.

Figure 2. 1 Map of Libya

To facilitate an understanding of the research context, the Driving forces–Pressure–State–Impact–Response (DPSIR) approach of the European Environmental Agency (EEA) can be adopted (Figure 2.2)

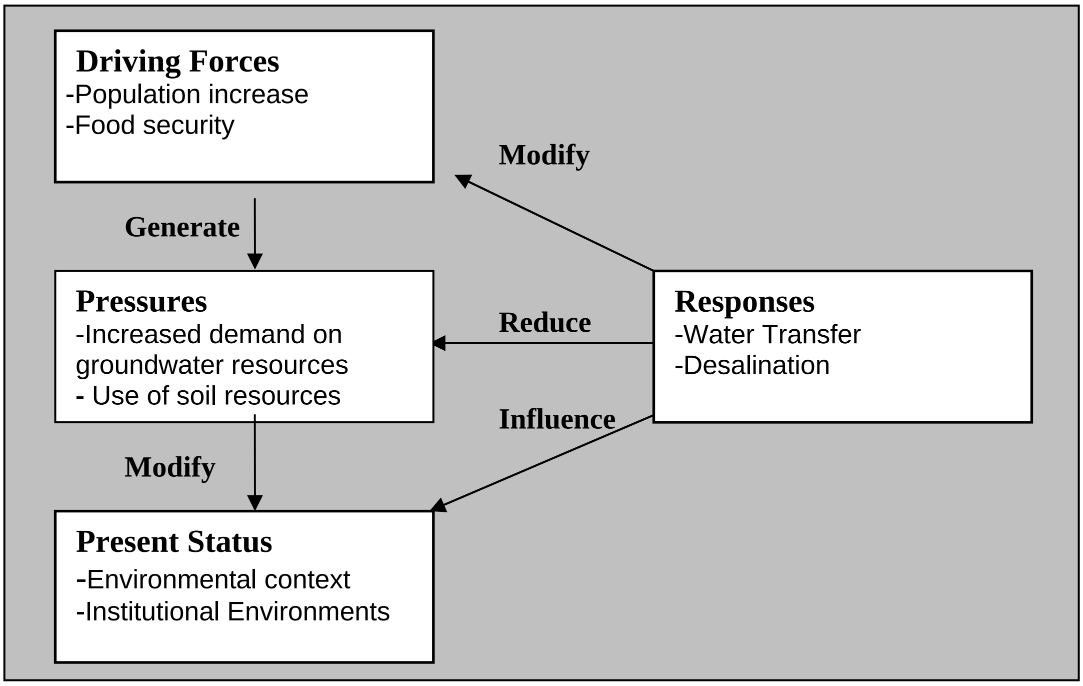

Figure 2. 2 Conceptual framework for the research context

2-2 Driving Forces

In Libya, the needs and demands of a rapidly increasing population have been the principal driving force in the allocation of land resources to various kinds of uses, with food security as the primary aim. Population pressure and increased competition among different land users have emphasized the need for more effective land-use planning and policies. Rational and sustainable land use is an issue of great concern to the Libyan government and to land users interested in preserving the land resources for the benefit of present and future populations. An integrated approach to planning and management of land resources is a key factor to implementing solutions which will ensure that land is allocated to uses providing the greatest benefit.

Population growth is a primary factor driving increases in the demand for food and agricultural products. The total population of Libya has dramatically increased over the last three decades. It was only 1.986 million in 1970 while in 2003 it had rise to 5.551 million. Compared with 1970, the total population had doubled by 1980 and trebled by 2003 (FAOSTAT, 2004).

While the population is rapidly growing, the country is experiencing declining farm populations and declining land area farmed. In 1970 the urban population in Libya was 45 per cent of the total population whereas in 2003 it increased to 86 per cent (FAOSTAT, 2004) (Figure 2-2).

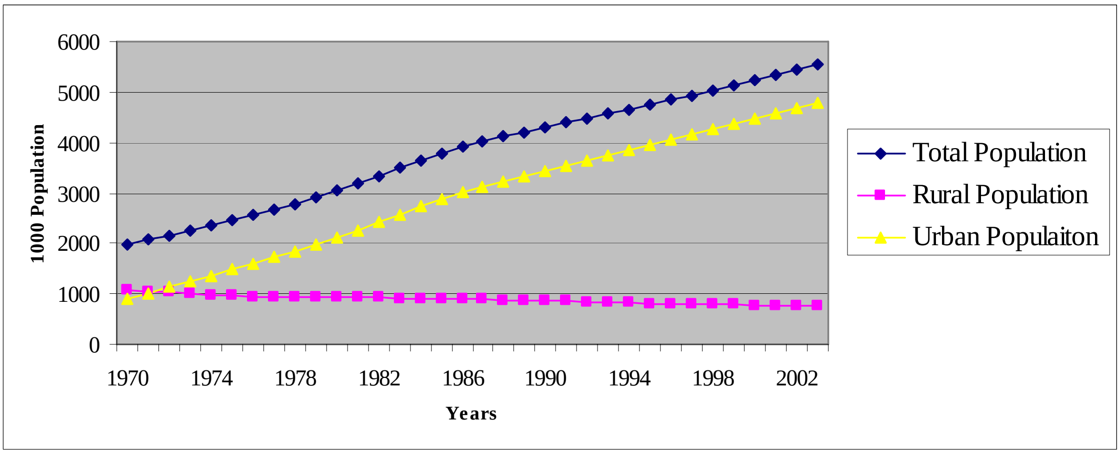

Figure 2. 3 Population growth in Libya from 1970 to 2003

Source: FAOSTAT (2004)

The effect of an increase in urban population is to decrease the agricultural population. The agricultural population was 729 thousand (37 % of the total population) in 1970, whereas in 2003 the agricultural population was 275 thousands (5 % of the total population); the non-agricultural population increased from 1.257 million (63 %) to 5.276 millions (96 % of the total population) (Figure 2.4).

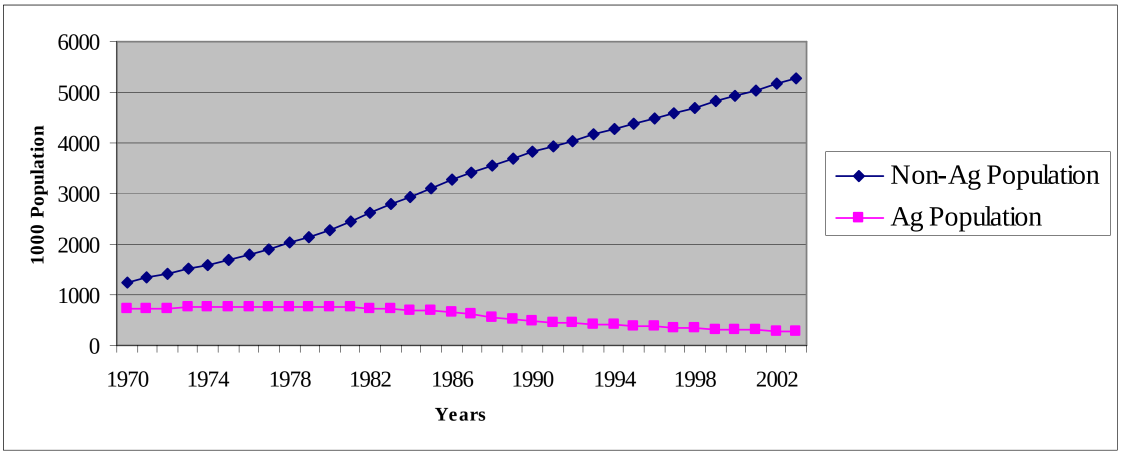

Figure 2. 4 Agricultural and non-agricultural population in Libya from 1970 to 2003

Source: FAOSTAT (2004)

To assess the population components of Libya's food security, we have to understand the following demographic characteristics:

- The population increase during the first three decades since 1960s when oil discovered. It has created a population momentum, which will drive Libya's population growth in coming decades;
- the extreme spatial distribution of the population, which is a consequence of the country's uneven cropland distribution, climate, and physical environment;
- the high population density in relation to vital natural resources, such as land and water.

The consequence of this increase in population is higher demand on water and food. The food supply in 2002 was five times that of the food supply in 1970 for the cereal crops (wheat, barley and maize) (Figure 2.5). High population growth and the discovery of oil in Libya led large numbers of Libyans to migrate from rural to urban areas. This led to increased pressure on the services of the main cities such as Tripoli and Benghazi, as well as increased the pressure on the groundwater resources in the coastal strip.

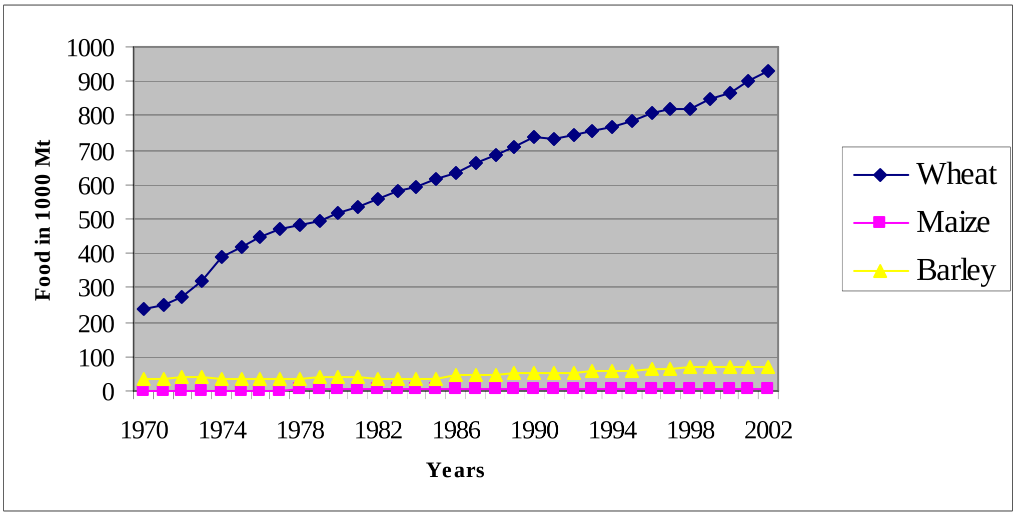

Figure 2. 5 Food supply in Libya from 1970 to 2003

Source: FAOSTAT (2004)

2-3 Pressures

Since the demand has increased on the food supply, the irrigated agricultural area has increased. Compared with 1970, the irrigated area almost doubled by 1987 and trebled by 1990. However, since 1990 the irrigated area has not increased (Figure 2.6). This was due to the lack of additional water resources.

The increasing pressure on water and soil resources has led to degradation of both resources. The intensive use of groundwater resources has caused decline in underground water, resulting in sea-water intrusion. The introduction of sea-water into costal aquifers has led to the salinisation of the lower part of those aquifers. Faced with these problems, the government had to form and implement the appropriate policies (responses) to reduce the pressures, influence present status and modify the driving force.

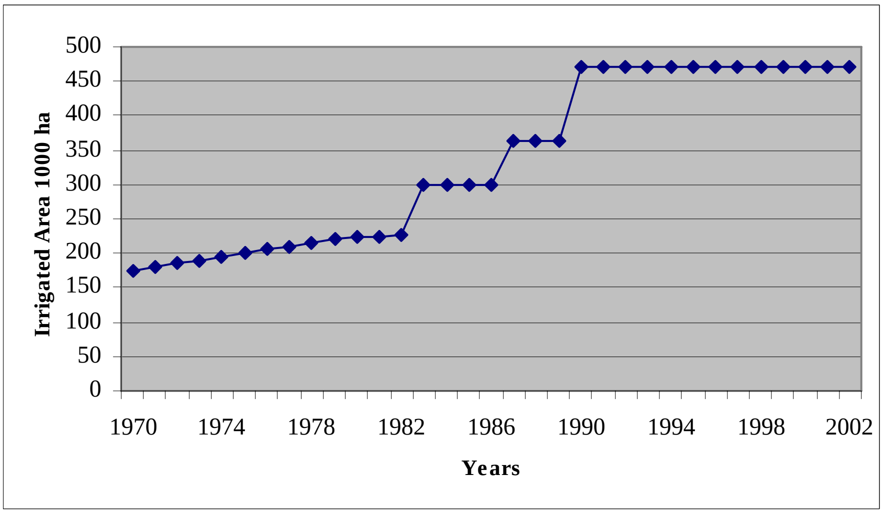

Figure 2. 6 Irrigated Agricultural Area from 1970 to 2003

Source: FAOSTAT (2004)

2-4 Present Status

It is vital to identify the present status of agricultural development. This includes development within both an environmental and institutional context. With relation to the environmental context, very important questions have to be examined. For example, what is the state of the soil, water resources and climate conditions?

2-4-1 Environmental Context

2-4-1-1 Soil Resources

Extensive soil studies (approximately 250) have been conducted in Libya over the last four decades. Emphasis has been placed mainly on the northern part of Libya and on small scattered areas in the southern desert. The present soil survey reports and maps differ in their content, types of maps, scale of mapping, classification systems used, methods of soil analysis, and the criteria on which the interpretation of data is based. The major soil classification systems used in these reports are the USA Soil Taxonomy, the modern soil classification of Russia, the French soil classification, and the FAO/UNESCO system.

The main soil orders in Libya are Entisols, Aridisols, Mollisols, Alfisols, Vertisols, and Inceptisols (Selkhozpromexport, 1980; Suliman, 1989; Mahmoud, 1995; FAO & UNESCO, 1998; Soil Survey Staff, 1999). In general, apart from the Jabal Akhdar and some of the Tripoli Mountains (Jabal Nafusah), Libyan soils are Entisols and Aridisols. The main orders of Libyan soils are shown in Table 2.1.

Table 2. 1 The main soil orders in Libya

Soil orders (American classification)	**Russian Classification**	**FAO & UNSCO Classification**
Entisols	Reddish Brown Arid	Regosols
Aridisols	Serozems, Desert Soils	Luvisols
Alfisols	-Red Ferrisiallitic Typical	- Chromic Luvisoils - Calcic Chromic Luvisols
Mollisols (Rendolls)	- Rendzinas Dark - Red Rendzinas	- Rendzins Leptosols
Inceptisols	Siallitic Cinnamonic	- Cambisols

Source: (Selkhozpromexport, 1980; Mahmoud, 1995)

2-4-1-2 Climate

The Libyan climate is influenced by the Mediterranean Sea to the north and the Sahara desert to the south, resulting in an abrupt transition from one kind of weather system to another. Three broad climatic divisions can be observed:

- The Mediterranean coastal strip, with dry summers and relatively wet winters;

- The Jabal Nafusah and Jabal Akhdar highlands, experiencing a plateau climate with higher rainfall and low winter temperatures including snow on the hills;
- Moving south to the interior, pre-desert and desert climatic conditions prevail, with torrid temperatures and large daily thermal amplitudes. Rain is rare and irregular and diminishes progressively towards zero in the south.

The average annual rainfall varies from region to region according to the geographic position and the topography. Generally, the average rainfall is the highest (600 mm/year) in the Jabal Akhdar, whereas the lowest average rainfall is in Aljgbob and Mrada in the south (Pallas, 1980; Alghraiani, 1993; Salem, 1992). Rainfall occurs during the winter months (October to March), but great variability is observed over space and time (year to year). For example, the total rainfall at Benghazi in 1980 was 158 mm, whereas in 1981 it was 469 mm (Benina Meteorological Report, 2002). The temperature is lowest in January and starts to increase gradually from February until July and August when the highest temperatures are reached. The temperature also varies from region to region. In the coastal region, the monthly average temperature is between 23 °C – 25 °C. In the semi-desert regions the monthly average temperature is between 25 °C - 28 °C, whereas, the maximum temperature in the desert regions may exceed 30 °C (Benina Meteorological Report, 2002). The annual humidity at the coast is between 70 per cent and 80 per cent.

Prevailing winds are north-easterly in north west Libya and north-westerly in the rest of the country. In the spring and autumn, strong southerly winds known locally as "Ghibli" blow from the desert, filling the air with sand and dust raising the temperature to approximately 50° C. These strong winds are a major erosion factor in the desert, transporting sand from one place to another.

The high temperatures experienced in the coastal area reduce with altitude in the hills. In summer coastal temperatures near sea level can exceed 43°C, but in the winter these can fall to freezing point (Pallas, 1980; Salem, 1992; Alghraiani, 1993).

2-4-1-3 Water Resources

Libya is an arid country with an average annual rainfall of less than 100 mm, falling over 93 per cent of its surface area. However, there is important potential for groundwater development; but while most of the population, and consequently the water demand, is concentrated within a narrow strip along the Mediterranean coast, most of the groundwater potential is located to the south in the desert areas (Pallas, 1980). Water resources can be divided into the surface and groundwater components.

- **Surface water**

The dominant features of rainfall are scantiness and variability in intensity from year to year. Therefore, a very small amount of runoff reaches the sea and it considered that most of the runoff water is either evaporated or infiltrated in the wadi beds for recharging the underlying aquifers. The total mean annual runoff water calculated is roughly estimated at 200 million m^3 yr^{-1}(Pallas, 1980; Elasswad, 1995). Even assuming that 50 % of the water can be intercepted and forms a resource, these 100 million m^3 yr^{-1} would represent only 1 – 2 % of the water resources (Pallas, 1980). Sixteen dams have been built to intercept water runoff. Salem (1992) stated that a combined total storage of these dams is 387 million m^3 yr^{-1} .

- **Groundwater Resources**

The main water resource in Libya is groundwater. This constitutes approximately 98 per cent of the total amount of available fresh water in the country. The demand for water has more than doubled between 1977 and 1994, thus, intensifying pressure on this finite resource (Alghraiani, 2003).

Libya has five principal regions with substantial water resources, Jifarah Plain and Jabal Nafusah region; the Middle zone; Al Jabal Al Akhdar region; Fezzan region and Kufrah and Assarir region (Pallas, 1980; Jones, 1996) (Figure 2.7).

1. Jifarah Plain and Jabal Nafusah Region

This region, which is located in the northwest part of Libya, represents more than 80 per cent of the irrigated area in the country. The early Cretaceous/Triassic formation contains aquifers with varying degrees of discharge and depth. Water quality ranges from good to saline. The estimated discharge of wells in the shallow aquifers is 2-3 m^3 sec^{-1}. Discharge from the artesian wells is estimated to be around 350 m^3 hr^{-1}.

The current groundwater production in this region is approximately 1750 million m^3 yr^{-1} with salt contents of 400-1000 ppm. The annual recharge rate is estimated to be around 300 million m^3 yr^{-1}. The recharge is mainly from the rainfall on Jabal Nafusah, south of the Jifarah plain. Therefore, this aquifer is greatly over exploited and non-sustainable.

2. The Middle Zone

This region constitutes a transition between Jifarah Plain in the west, Al Jabal Al Akhdar and Fezzan and Alharuj Aswad in the south. The region is characterised by Tertiary/Quaternary formations containing shallow aquifers especially along the coast. The depth of these reservoirs ranges between 30 and 100 m. There are also deep reservoirs present in the late Cretaceous formations, with depths ranging from 100 to 800 m from the soil surface. There are also Cretaceous aquifers ranging in depth from 70 to 250m from the soil surface. The current water use is around 400 million m^3 yr^{-1}.

3. Al Jabal Al Akhdar Region

This region comprises the Benghazi Plain as well as the Al Jabal Al Akhdar area and extends to the eastern border with Egypt. The main groundwater reservoir of this area is present in layers of Tertiary limestone formation, sitting on an impermeable layer of late Cretaceous formation. It is characterised by the existence of faults through which water moves northwards, towards the Mediterranean Sea, at a rate of approximately 250 million m^3 yr^{-1}. Another portion of the water in this reservoir moves southward at a rate of 150 million m^3 yr^{-1}. The estimated recharge is approximately 340 million m^3 yr^{-1}.

4. Fezzan Region

This region is situated in the south western part of Libya. Groundwater in this region is present in two main aquifers. The first aquifer is the Nubian sandstone aquifer in the early Cretaceous/Triassic formation, particularly in the western part of the region. The thickness ranges between 50 and 300m. In some places it extends to a depth of 800m.

The second aquifer is present in Devonian and Cambro-Ordovician formations. It is very deep (up to 2000 m) with a thickness ranging between 300 and 2000 m. The Devonian sandstone is separated from the Cambrian-Ordovician by clay layers, particularly in the western part of the basin. The groundwater recharge in this region is zero due to lack of rainfall.

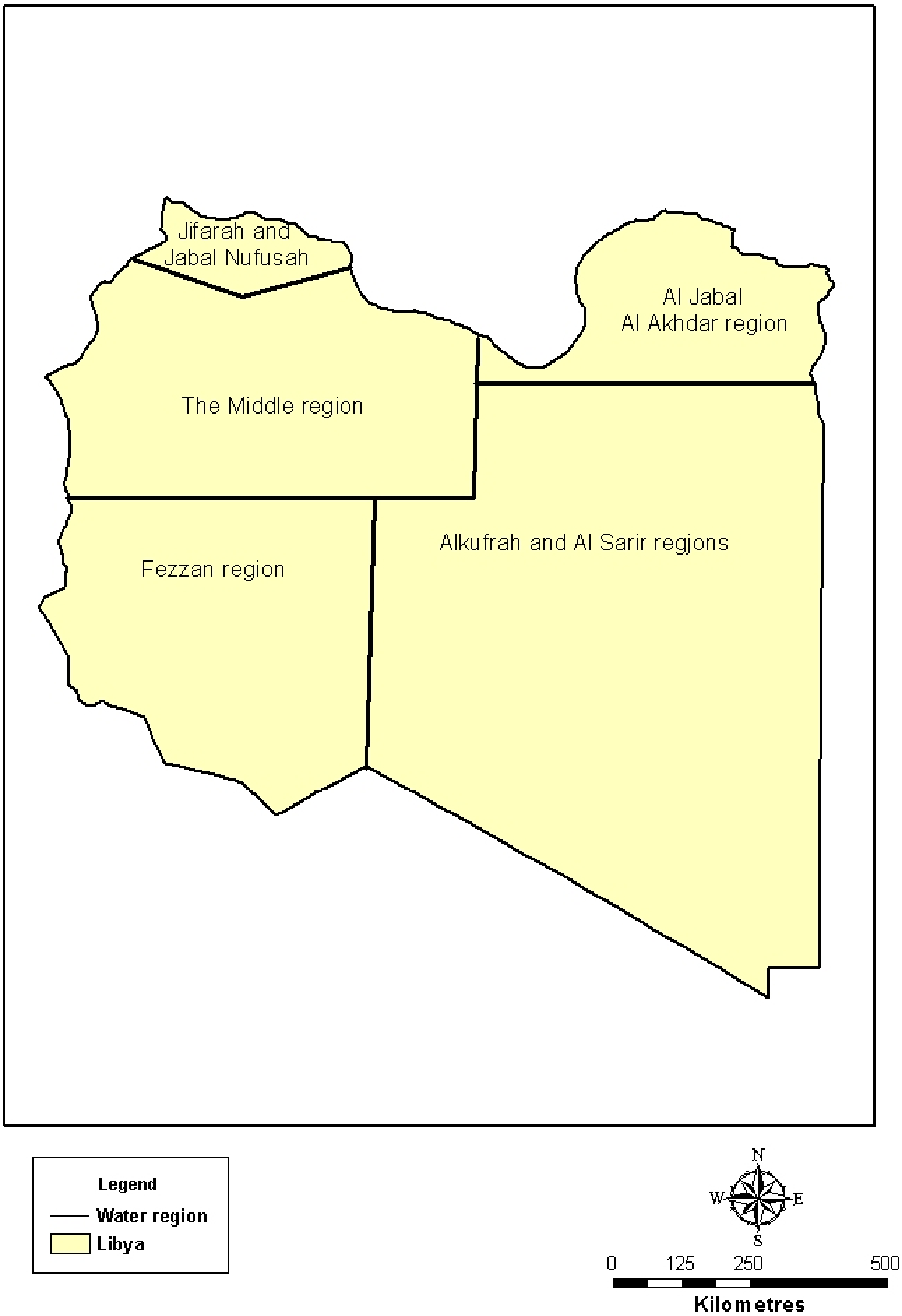

Figure 2. 7 The location of water regions in Libya

5. Al Kufrah and Assarir Region

This region consists of the south-eastern part of the country and is characterised by aquifers in the Nubian sandstone formation (Pallas, 1980). This formation is very thick and extends to about 3000 m depth, especially at the middle of the Al Kufrah basin. There are also aquifers in the north, near to Assarir, in the Tertiary sandstone formation. The water quality of this region is generally good with total dissolved salts less than 0.5 g/l in Al Kufrah region and 0.5-3.5 g/l in most of Assarir region. The water in the deep layer is not renewable and the amount that can be safely withdrawn annually in Al Kufrah and Assarir region is estimated to be around 2610 million m^3 for at least the next 50 years. Current use is estimated to be around 1500 million m^3 including the first stage of the Great Man-Made River (discussed in section 2-5-1).

- **Summary**

The lack of surface water resources, limited rainfall rates, and the escalating water demands in Libya during the past 20 years led to severe pumping and over-exploitation of the local groundwater aquifers. These aquifers are of limited extent and annual recharge in the coastal area. They have been exposed in several locations to unacceptable levels of piezometric declines and sea-water intrusions (Alghraiani, 1993). The remaining options to meet water demand in the coastal area are mass transfer of fossil water from the dessert aquifers to the coastal area and/ or large scale sea-water desalination.

2-4-2 Institutional Environments

2-4-2-1 Political Institutions

The overall responsibility of Agricultural development and fund allocation for Agricultural development rests with the General People's Committee (GPC).

The GPC implements the decisions and recommendations from the General People's Congress. The Secretariat of Agriculture (Ministry of Agriculture) was the ministry responsible for agricultural development and animal wealth. In 1995, the Secretariat of Agriculture was split into the Secretariat of Agriculture and the Secretariat of Animal Wealth.

In 1999 as a means of reform and decentralisation, the country was divided into 31 local authorities. These local authorities are called Sha'abiyyat, which is the plural of sha'abiyya (which is the locality conglomeration) and the cornerstone of the new reform. The local authority has the overall responsibility of planning locally, which in many cases contradicts with the central government. As a result of these reforms, the Agriculture Ministry and Animal Wealth were reduced to the General Agriculture Organisation (GAO) within the Ministry of Service alongside the Health and Education ministries (Law No (21), 1999) and its executive regulation No (49), 2000. The government claims that these reforms are to simplify and facilitate delivery of services to citizens at the local level.

The responsibility of water utilisation, assessment and monitoring for all water resources in Libya rests with the General Water Authority (GWA), whilst the General Agriculture Organisation (GAO) is responsible for the development of irrigated agriculture and the implementation of major projects. The Great Man-Made River Authority (GMRP) was created in October 1983 and invested with the responsibility of extracting water from the aquifers in the south and conveying it by the most economical and practical means for use in the Libyan coastal belt. Water from the desert well fields is planned to be used for municipal and industrial purposes, but principally for agricultural purposes. Figure 2-8 shows the different relation between the decision-making institutions

(General People's Congress, 2005). As shown in Figure 2.8, the GPC is responsible for policy formulation and implementation in Libya. The responsibility for agricultural development and major irrigation projects rests with the GAO. The GAO co-operates with the Agriculture Research Centre (ARC), National Authority for Scientific Research (NASR) and GWA in directing agricultural research. All research centres and organisations in Libya are directly controlled by the GPC.

The ARC in Libya dates back to the early part of the last century during the colonial era, when "Centro Sperimentale Agrario E Zootecnico della Libya" at Sidi El Masri near Tripoli was established to serve the Italian agricultural settlers. In the early 1950s to late 1960s, the Ministry of Agriculture was initiated and ARC became affiliated to the Directorate of Plant and Animal Production, with major changes in goals and organisation. In 1970 the ARC was established by the Ministry of Agriculture to serve as an authorised umbrella organisation for the implementation of agricultural research in the country, with an adopted national work plan. Four regional research branches were initiated according to the altitude, climate and agriculture activity of a region (El-Azzabi and Mahmoud, 1999).

El-Azzabi and Mahmoud (1999) concluded that the agricultural research institutes have attempted to set up research programme and to undertake a recruitment and training effort in accordance with the country's agricultural potential and development plan. However, their strategy is hampered by the limited collaboration with universities, the insufficient and unsustainable financial resources, the lack of technicians and support staff, and restricted bilateral and international cooperation.

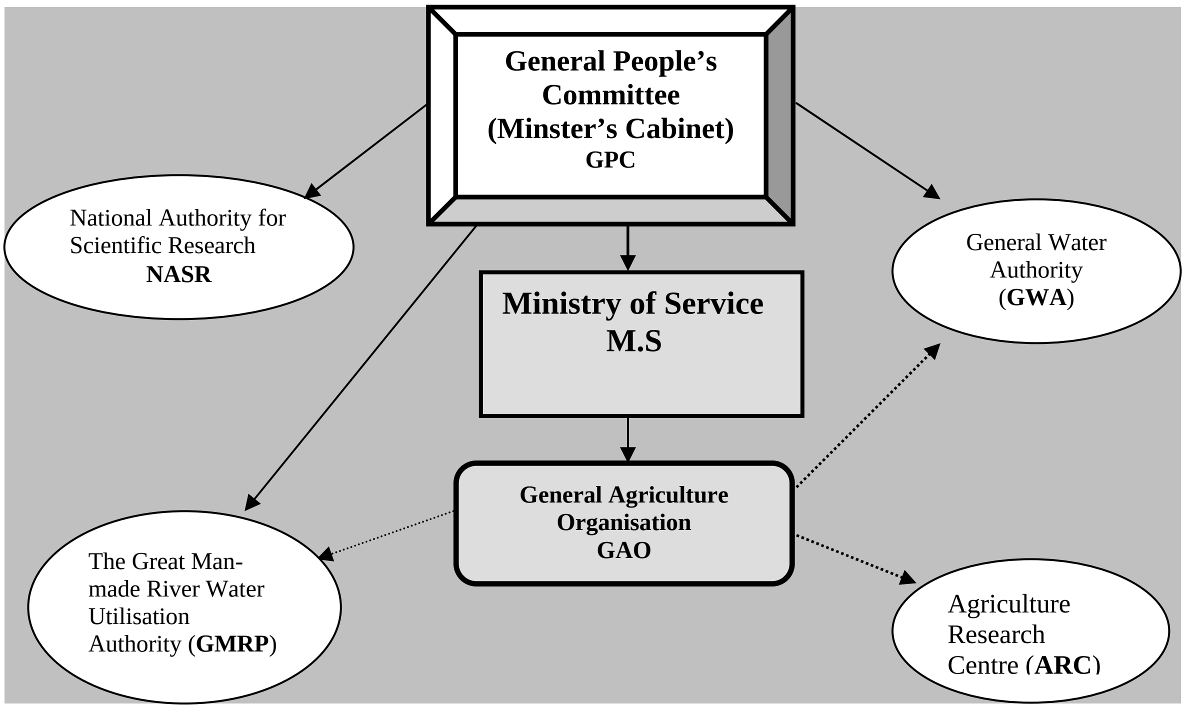

Figure 2. 8 Institutional Environment

2-4-2-2 Socio- Political Considerations

It is widely believed that the history of Libya's agricultural development has been closely related, although inversely, to the development of its oil industry. In 1958, before the era of oil wealth, agriculture supplied over 26 per cent of GDP (ARC, 1990). Although gross levels of agricultural production have remained relatively constant, increasing oil revenues have resulted in a decline in agriculture's overall share of national income. Thus, by 1962, agriculture was only responsible for 9 per cent of GDP, and by 1978 this Figure had fallen by a further 2 per cent. In addition, there was a rise in food imports. In 1977 the value of food imports was more than 37 times greater than it had been in 1958. Therefore, a large part of the rising oil wealth between 1960 and 1977 was spent on imported food products (Jindeel, 1978).

The strong position of agriculture in 1958 masked a high level of general poverty. Agriculture during the 1950s was characterised by low level productivity and income. The advent of oil wealth provided many peasants with opportunities to engage in less exacting and more remunerative work in the urban areas, resulting in a mass rural migration to the cities. The appeal of the cities was compounded by the fact that Libya is not a country with great agricultural resources. The number of peasants who gave up farming to look for jobs in the oil industry and in urban areas rose dramatically throughout the period 1955-1962.

Since 1962, Libyan governments have paid considerable attention to agricultural development. The government has given inducements to absentee landlords to encourage them to put their land to productive use and initiated high agricultural wage policies to stem the rural-to-urban flow of labour. These policies have met with some success. Production levels began to rise slightly, and many foreign workers were attracted to the agriculture sector.

Agricultural development became the cornerstone of the 1981-85 development plans, which attached high priority to funding the GMRP project. Agriculture credit was provided by the National Agriculture Bank. The substantial amount of funds made available by this bank may have been a major reason why a considerable number of the labour force, nearly 20 per cent in 1984, chose to remain within the agricultural sector (ARC, 1990).

In recent years food security has been given the priority in the country's policy. The aim is to attain self-sufficiency for some agricultural products that contribute largely to the diet of most Libyans, thus decreasing the requirements for food imports (GMRP, 1990). The major agricultural products in Libya are: cereals, legumes, vegetables, fruits, meat, and dairy products. When comparing the agriculture production for 1980 with the agricultural production for the year 2000 (Table 2.3), it appears that self-sufficiency for vegetables is almost achieved for the year 2000, but not for the rest of products.

The recent development in agriculture is directed towards increasing the total production of cereals in order to reach self-sufficiency. As appears in Table 2.3 the deficiency between production and self-sufficiency for cereal was 21 per cent in 2000. The implementation of the irrigation projects (GMRP) will contribute to total production and, therefore, decrease the deficiency in these products.

Table 2. 2 Total Agricultural Production 1980 and 2000

Products	1980				2000			
	Total Production (1000 tons)	Total Needs (1000 tons)	Deficiency (1000 tons)	Percentage self - sufficiency	Total Production (1000 tons)	Total Needs (1000 tons)	Deficiency (1000 tons)	Percentage self - sufficiency
Cereals	366,000	474,000	108,000	77.2	697,000	882,000	185,000	79
Legumes	10,000	16,000	6,000	62.5	32,000	34,800	2,800	91
Vegetables	346,500	352,500	14,000	98.2	638,000	638,000	-	100
Fruits	197,000	226,000	29,000	87.1	312,100	332,000	20,000	93.9
Meat	14,000	18,080	4,080	77.4	25,000	36,540	11,540	68.4
Dairy products	70,930	248,210	177,280	28.5	110,050	331,290	221,240	33.3

Source: Agriculture Research Centre (2000)

The increase in the agriculture production has been due to an increase in the extent of irrigated areas. However, this increase in production can be associated with a number of predominant soil-related issues, particularly in some parts of the north west of Libya. One of the most important issues is the increased soil salinity. In many areas, rising water tables have led subsequently to waterlogging and associated salinity problems. This has happened where drainage development has not kept pace with irrigation development, or where maintenance of drainage facilities has largely been neglected. Therefore, it is a vital that these soil related issues to be considered in the design of future irrigation schemes and their subsequent operation.

2-5 Response

As noted in previous sections there is population growth and consequently increasing demand on food and water. Libya relies heavily on groundwater to satisfy its ever-increasing water needs, with minor contributions from surface run-off and dams (Salem, 1992). As described in the water resource section, a serious water deficit has existed for several years. This deficit will undoubtedly increase in the future due to the continuous population growth and corresponding increase in water requirements for domestic, industrial and agricultural purposes (Abufayed and El-Ghuel, 2001). This exerts pressure on the decision-makers to form effective policies to face these challenges. The government can select from two options, water transfer or desalinisation.

2-5-1 Transfer of Water

Libya is embarking on an ambitious project for the development of its water resources. This project is called the Great Man-Made River Project (GMRP). It will transfer 6.18 million m^3 of water per day (around 2250 million m^3 yr^{-1}), from Al Kufrah and Assarir and Fezzan regions. Water will be transferred to the coastal areas, through a system of pre-stressed concrete pipes, with a length of some 4500 km (Figure 2-9). GMRP (1990) concluded that transfer of water is the cheapest option at the time to meet water requirement of the country. In particular, transfer of water is cheaper than water desalinisation. Elasswad (1995) stated that the estimated cost per m^3 is about $ 0.20 and states that the cost is very small compared to other sources such as coastal desalinisation where the cost is approximately $ 3.75 per m^3.

The GMRP is planned in five phases. The first phase, the largest, is already constructed and consists of a system that will extract and carry two million cubic metres of water daily to the coastal region. However, the system is designed to be expanded to carry 3.68 million m^3 of water daily in the future.

The water will be carried to Sirt and Benghazi from wellfields at Sarir and Tazirbu, with a future expansion to the wellfields in Kufrah (GMRP, 1990). The second phase consists of a system that delivers one million m^3 of water daily from wellfields in Fezzan region to the western coastal belt and in particular to Jifarah Plain. It is designed to accommodate a further one million m^3 a day in the future (GMRP, 1990). The third phase is an anticipated expansion of the first phase. The water flow will be increased by 1.68 million m^3 daily. The additional water will be obtained from Kufrah (GMRP, 1990). The fourth phase will carry 200,000 m^3 to Tubruq from Ajdabiya. The fifth phase consists of two stages. The first stage connects phases one and two by linking a conveyance line between Sirt and the Jifarah Plain to deliver one million m^3. The second stage of phase five expands the second phase system by incorporating two additional wellfields to supply one million m^3 of water a day.

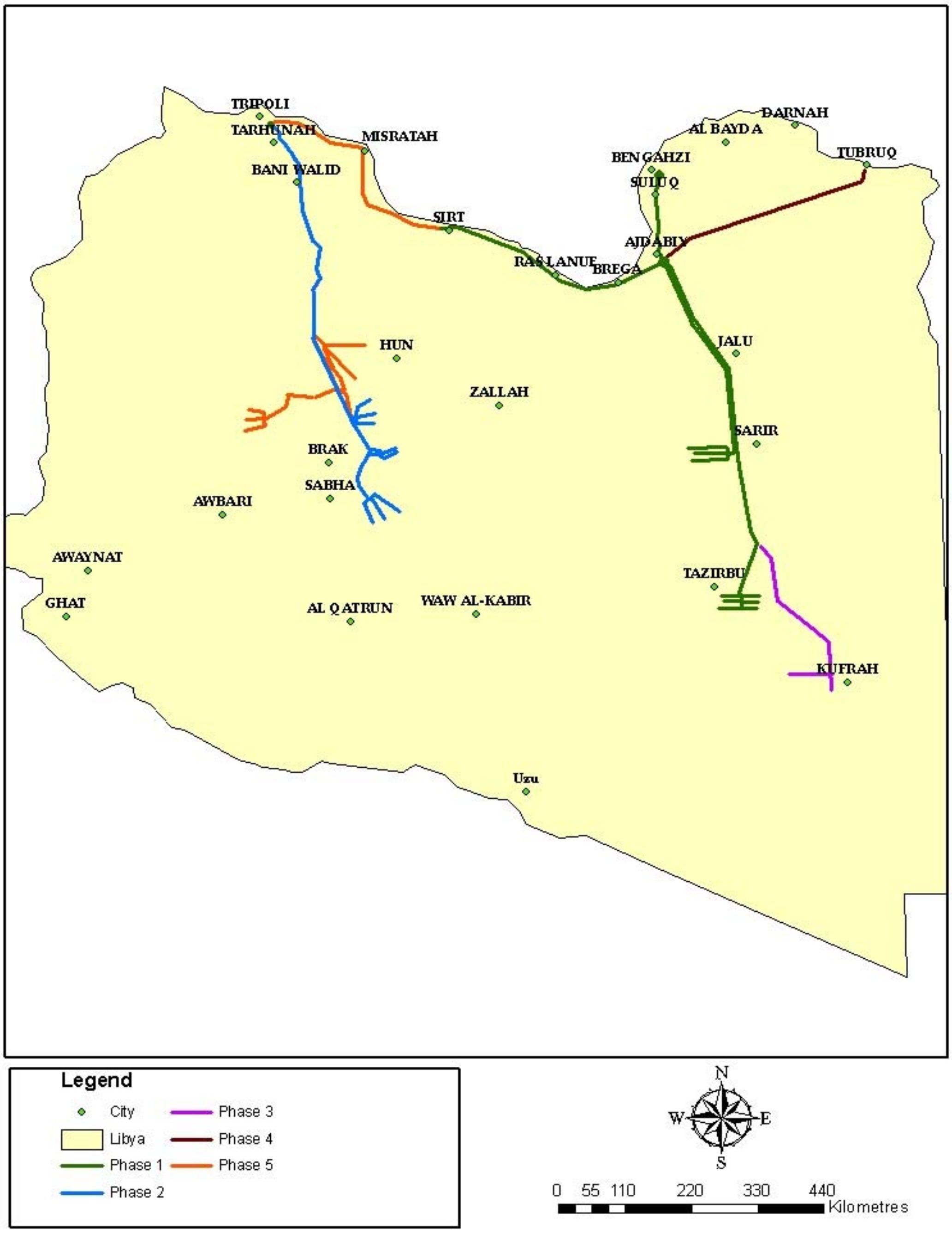

Figure 2. 9 The Great Man-Made River Project (GMRP)

2-5-2 Desalinisation

Groundwater quality is deteriorating in the coastal strip where the majority of the population live and where most of the country's industrial plants are located (Elasswad, 1995). This puts pressure on the policy makers to form plans and policies to counter this problem. With the country's long Mediterranean coastline, desalination presents an obvious potential.

Desalination technologies have been used in Libya since the early sixties, mainly by oil companies in water shortage locations (Abufayed and El-Ghuel, 2001). Since then the Libyan government has constructed a number of desalinisation plants at different locations along the coast. In 1996 the total number of desalination plants exceeded 400 with total installed capacity of over 0.65 million m^3 day^{-1}. Desalinated water is used mainly for municipal and industrial purposes (Abufayed and El-Ghuel, 2001).

The application of desalination technologies has met with both successes and problems, the latter resulted in the actual capacities being only a small fraction of what was anticipated (Kershman, 2001). Table 2.4 shows the difference between the full operational capacities of some desalination plants and the existing capacities.

Abufayed and Ghuel (2001) summarised the major problems associated with the desalination process: contracting and technical problems, and operational and maintenance problems. The technical contracting problems occurred due to limited local experience in the early sixties and seventies. Consequently, local constraints and factors were given little consideration in the design criteria, process technology, operation, and maintenance system. The operational and maintenance problems are caused by lack of experienced personnel, spare parts and materials.

Table 2. 3 Potential and actual capacity of selected desalinisation plants in Libya

Location	Potential Capacity $m^3\ day^{-1}$	Existing Capacity $m^3\ day^{-1}$	% Existing capacity of the total
Benghazi	24,000	10,000	41
West Tripoli	23,000	10,000	43
Tobruk I	24,000	20,000	83
Homs	53,000	40,000	75
Bomba	30,000	18,000	60

Source: (Kershman, 2001)

Alghraiani (2003) compared water transfer and desalination in North Africa, with particular reference to Libya. Alghraiani concluded that since in 1970s and 1980s; seawater desalination has become cheaper than transferred groundwater for the Saharan and Sub-Saharan aquifers, at least in the case of the Libyan GMRP. He added that Libyan authorities must reconsider their position on completion of remaining stages of the GMRP (Alghraiani, 2003).

GMRP (2003) responded to Alghraiani's concerns by stating that economics was the sole criterion of the comparison neglecting other factors such as environmental impact and water use. GMRP added that the Libyan experience with seawater desalination is not encouraging, due to low operating capacities in comparison with full operating potential.

In conclusion, most of the studies of desalinisation in Libya agree that desalinisation has good prospects and can play an important role in securing water supply. However, there is a disagreement about whether desalinisation can be considered as the first source in the short term or not (Elasswad, 1995; Abufayed and El-Ghuel, 2001, Kershman, 2000; GMRP, 2003).

2-6 Summary

The Libyan government policy is to continue to support the transfer of water from the desert as the first option for securing a water supply and as a second option the development of unconventional water resources, namely, desalination (CWSS, 1999). The water transported from the south of the country is planned to be utilised in producing cereal crops (barley, wheat, maize and sorghum).

Efficient management of natural resources is essential for ensuring food supplies and sustainability in agricultural development. The task of meeting the demands of increasing populations without affecting the ecological assets for the future generations should be given top priority by land use planners in Libya. Assessing the suitability of land for these crops is a vital and essential part of land use planning and agricultural development in Libya especially in the parts of the country where the irrigation projects are planned.

There is a pressing need to develop a land evaluation framework if the GMMR transfer water is to be well used. The aim of this research is to develop a prototype for land evaluation in Libya taking into account the objectives of the Libyan agriculture policy and data availability. The north east of Libya is selected to be a case study for this research. In the next sections, the study area is described to form a background for reviewing the land evaluation methodologies and the selection of the appropriate one for the Libyan environment.

2-7 Conclusion

Population growth is a major driving force of food demand in Libya. The demand of food has rapidly increased. The responses from the government have been to transfer water from the desert aquifers to the coastal area and water desalination is considered as a future alternative. It is planned to utilise 86 per cent of the transferred water for crop production (barley, wheat, maize and sorghum). In order to the transfer water to be well used, there is urgent need to develop land suitability assessment.

Therefore, there is a great need to develop land evaluation methodology for Libya. This raises questions such as what is the best methodology for the Libya and how can it be developed in such environmental conditions. In the next chapter, land evaluation methodologies are reviewed to select the best suits the Libyan context.

3

Critical Assessment of Land Evaluation Techniques

This Chapter reviews land evaluation approaches. It discusses the philosophy behind each approach and identifies the strengths and weaknesses in each methodology. In addition, the appropriate land evaluation approach is selected, taking into consideration the limitations of data availability and the suitability of the results for land use planning.

3-1 Land Evaluation Concepts and Definition

Land evaluation is the process of predicting the potential use of land on the basis of its attributes. Also it is the process of estimating the potential of land for alternative kinds of use. The basic feature of land evaluation is the comparison of the requirement of a land use type with the resources or characteristics offered by the land (Dent and Young, 1980). Land evaluation as a term has been developing over recent decades. Stewart (1968) defined land evaluation as "the assessment of the suitability of land for man's use in agriculture, forestry, engineering, hydrology, regional planning, etc". Many disciplines have contributions to make to land evaluation in its widest sense.

The term "land evaluation" was used in 1950 at the Amsterdam Congress of the International Society of Soil Science. Until about 1970 "land classification" and "soil survey interpretation" were used instead of the term "land evaluation".

Vink (1975) defined land classification as "all those groupings of soils that made from the point of view of the people that are using the soils in practical sense" (van Diepen, 1990). Land classification is not soil classification, which refers to the scientific nomenclature of soils. The term "land evaluation" was revived in 1968 at the Symposium on Land Evaluation in Canberra, organised by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The broad definition by Stewart was given on that occasion and, with a similar connotation of the term was propagated by FAO's Framework for Land Evaluation (FAO, 1976).

It is essential to clarify the definition which will be used in this chapter as there are many definitions in use. The holistic concept of land was recognised in the Framework for Land Evaluation (FAO, 1976) whereby *"land comprises the physical environment, including climate, relief, soil, hydrology and vegetation, to the extent that these influence potential for land use. It includes the results of past and present human activity, e.g. reclamation from the sea, vegetation clearance, and also adverse results, e.g. soil salinisation".*

This definition is repeated implicitly in Chapter 10 of UNCED (1993), and formally described by FAO (1995). It reads:

" Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserves, the plant and animal populations, the human settlement patterns and physical results of past and present human activity (terracing, water storage or drainage structure, roads, buildings, etc.)."

According to FAO (1976, 1985) land has attributes, characteristics, properties and qualities:

- Land Attribute is a neutral, over-arching term for a single or compound aspect of the land.
- Land Characteristic is an attribute which is easily noticed and which serves as a distinguishing element for different types of land; it may or may not have a practical meaning (e.g. soil colour or texture).
- Land Property is an attribute that already gives a degree of information on the value of the land type.
- Land Quality is a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specific kind of use (e.g. moisture availability)
- A major kind of Land Use is a major subdivision of rural land use considered in land evaluation and is of a qualitative or reconnaissance nature (e.g. rain-fed agriculture)
- Land Utilisation Type (LUT) is a kind of land use described or defined in a degree of detail (e.g. produce, market orientation, capital intensity, labour intensity etc.) greater than of a major kind of land use. It is to be noted that land utilisation types are defined for the purpose of land evaluation.
- Land Mapping Unit is a mapped area of land with specified characteristics. Land mapping units are defined and mapped by natural resources, e.g. soil, forest inventory.
- Requirements refer to the set of land qualities that determine the production and management conditions of a kind of land use.
- Limitations refer to the land qualities by means of diagnostic criteria which adversely affect a kind of land use.
- Diagnostic criteria these may be land qualities or characteristics that are known to have a clear effect on land use output or potential.

3-2 Land Evaluation Methodologies

Since 1950 the major trend in land evaluation systems has shifted from a broad sense to specific assessment, increasingly using quantification (van Diepen, 1990). In the following sections the land evaluation methodologies is assessed.

3-2-1 Land Capability Classifications

The "USDA Land Capability System" developed by the Soil Conservation Service of the US Department of Agriculture (1961) provides conceptual definitions of capability classes according to the limitations imposed by permanent properties of land. This system and its adaptations, such as the British Land Use Capability Classification, the Canadian Land Capability Scheme and the Dutch system, have been widely used around the world; and practically all soil survey in the USA contains a section on land capability (Davidson, 1992).

The USDA method has three levels in its capability classification structure: classes, subclasses, and units (Table 3.1). Soil mapping units are the foundation of the capability systems. The capability classes are the broadest category and indicate the degree of limitation. Soils are placed into one of eight capability classes which are distinguished on the basis of the range of alternative uses, with priority for arable cropping (I, II, III…etc). The soil limitation risk becomes progressively greater from class one to class eight. Subclasses are defined on the basis of four kinds of management problems i.e., (1) runoff and erosion, (2) wetness and drainage, (3) rooting and tillage limitations resulting from shallowness, drought risk, stoniness, or salinity, and (4) climatic limitations (IIe, IIw, IIs,IIc…etc). Capability units are subdivisions of the subclasses (IIe-1, IIe-2, and IIe-3….etc). The unit is a grouping of one or more individual soil mapping units having similar potential and continuing limitations of hazard (USDA, 1961). The grouping of soils into capability units, subclasses and classes was done primarily on the basis of their capability to produce common cultivated crops and pasture plants without deterioration over long periods of time.

Table 3. 1 Structure of land capability classification

Capability classes	Capability subclasses	Capability unit	Soil mapping unit
Arable I II III IV	IIw, IIs, IIc, IIe	IIe-1 IIe-2 IIe-3 etc	P series Q series R series
Non-arable V VI VII VIII			

Source: Dent and Young (1980)

The main focus of land capability classification is to classify the land on the basis of permanent limitations. It enables the land on a farm to be allocated rationally for the different kinds of use required, for example, rotational arable, permanent grazing, woodland, etc. It was originally intended for the planning of individual farms and it was a response to the serious soil erosion problems which occurred in the U.S.A, especially in the Mid-West. The prime aim of the classification was to express the risk of erosion and to indicate sustainable land uses (Davidson, 1992). The system is widely used both in developed and developing countries. The development of the system in application schemes in many countries is a clear indication of its value in aiding land use planning and management.

However, there are disadvantages of using this system. Firstly, it is subjective because there are no limiting value criteria set so that the allocation of the classes is simply the considered opinion of the evaluator. Secondly, there is no indication of the suitability for specific crops. Thirdly, it is negative; it emphasises the limitations rather than the positive potential of land and does not take into account possible soil improvements such as installation of irrigation and drainage systems. Finally, the rank order of potential land uses may give the wrong impression, for instance, the lower classes could be ideal and much valued for certain crops (McRae and Burnham, 1981).

3-2-2 Parametric system

The parametric approach combines the various soil and site properties (parameters) that are believed to influence yield using mathematical formula. Some parametric systems are simple whilst others can be extremely complex. Some have been widely accepted, usually because they have been incorporated into legislation on taxation, and others have been ignored (McRac and Burnham, 1981). Systems differ in the specific factors they include and in their mathematical manipulation. Three kinds of manipulation are recognised:

Additive e.g. $P = A + B + C$ **Equation 3. 1**

Multiplicative e.g. $P = A \times B \times C \times D$ **Equation 3. 2**

More complex functions, e.g. $P = A\sqrt{(B \times C \times D)}$ **Equation 3. 3**

where P is the parametric rating, score, or index and A, B, C, D are factors such as slope and the texture of the surface soil . These can either be direct values such as soil depth or the value can be related to a scale, for example, 0-100. The best known multiplicative system for rating the quality of land is the Storie Index Rating (Storie, 1976). The Storie Index, developed in California, had taxation as its main application. The Storie Index Rating can be calculated as follows:

$$SIR = A1 \times A2 .... An / 100 \text{ (n - 1)}$$ **Equation 3. 4**

where A1, A2, A3…….An are values of individual land properties on the scale 0 to 100. Parametric systems are easy to apply, attractively simple and quantitatively accurate and specific. However, their main purpose is for taxation and legalisation. Furthermore, they do not take the land use requirement into account. The reliability of the parametric system depends on the choice of determinant factors, their weighting, and the validity of the assumed interactions between factors. Mahmoud (1995) developed a parametric productivity rating for Libyan soils. Eleven soil properties were used to determine the productivity index rating:

$$\text{Productivity Rating} = (A \times B \times C \times D \times E \times F \times G \times H \times I \times J \times K) \times 100$$ **Equation 3. 5**

where A =soil texture of topsoil, B= soil compaction, C= soil depth, D= water table level, E=internal soil drainage, F= soil salinity, G = Exchangable sodium percentage, H= soil reaction, I= calcium carbonate percentage $CaCo_3$ %, J= soil erosion, K= soil slope. Each soil property was given a different value between 0-1 depending on the effect of that factor on agricultural production according to previous studies and experience in Libya. The results are calculated to produce suitability classes (Table 3.2).

This method was adapted from the Storie Index Rating, taking into account the local conditions to determine the properties included. Local experience was used to classify the soil suitability. The method is attractively simple and accurate. However, its results can be misleading , as they do not take into account the crop requirements which are vital for successful agricultural production. For example, the soils in Kufra (Pasmments) are suitable for apple production as suggested by the Productivity Rating but this is not truly the case because of the high temperature in that area which is highly unsuitable for the production of apples. Therefore, a parametric method is not generally appropriate for agricultural development in Libya.

Table 3.2 Productivity rating and suitability classes

Productivity rating %	Suitability class
0-20	Not suitable
20-30	Marginally suitable
30-60	Moderately suitable
60-80	Moderately Highly Suitable
80-100	Very High Suitable

Source: (Ben Mahmod, 1995)

3-2-3 USBR Land Classification for Irrigated Land Use

The U.S. Bureau of Reclamation designed this system for the selection of land for irrigation (USBR, 1951). The classification is a system based on economics for selecting and categorising the quality of land considered for irrigation development. There are certain principles for selecting lands for irrigation. In the Reclamation Manual (USBR, 1951) the principles are identified concerning predication of economic correlation, arability-irrigability analysis, and the permanent-changeable-factors.

The criterion for the assignment of suitability classes is the payment capacity which is the "residual available to defray the cost of water after all costs have been met by the farm operator" (USBR, 1951). There are six suitability classes in this system. Classes 1, 2, and 3 have respectively the highest, intermediate and lowest irrigation suitability and hence payment capacity. Class 4 is used, with appropriate suffixes, to indicate special land use e.g. fruit, rice or land with particular difficulties which can however, be overcome economically. Class 5 is a temporary designation for land requiring further special investigation before final allocation to another class and class 6 is land unsuited to irrigation (FAO, 1985).

In this classification *arable* land is "land which, in adequate-sized units and if properly provided with the essential improvements of levelling, drainage, irrigation facilities and the like, would have productive capacity, under sustained irrigation sufficient to:

i. meet all production expenses, including irrigation operation and maintenance costs, producing reasonable return for the farm investment;

ii. provide a reasonable repayment contribution toward the cost of project facilities;

iii. provide a satisfactory standard of living for the farm family." (FAO, 1985).

Another important definition to clarify in this classification is *irrigable* land. "It is the arable land under a specific project for which a water supply is or can be made available and which is provided with or planned to be provided with irrigation, drainage, flood protection, and other facilities as necessary for sustained irrigation" (McRac and Burnham, 1981).

The USBR system does not use a fixed methodology; instead general principles are applied to fit land classification to the economic, social, physical and legal patterns in an area. There is no indication of the physical suitability of individual crops or land use other than general conditions of soil for crop production. Furthermore, some qualities of land which affect the crop production such as climate are ignored.

The USBR system is based on the economics of land development. The intensity of observations and the stated "minimum requirements" are intended for US conditions, namely, those of high cost and high return (Dent and Young, 1980).

3-2-4 The FAO Framework for Land Evaluation

The FAO Framework is a set of methodological guidelines rather than a classification system and its aim is to provide structure for land evaluation projects to any environmental situation and at any scale. The Framework defines land evaluation as "*the process of assessment of land performance when used for a specific purpose, involving the execution and interpretation of survey data and studies of landforms, soils, vegetation, climate, and other aspects of land in order to identify and make comparison of promising kinds of land use in terms of their applicability to the objectives of the evaluation*" (FAO, 1976). The principles of the Framework are to describe the possible kinds of land use, to estimate land requirements, and to survey the area to map the distribution of these requirements (Dent and Young, 1980).

The Framework describes a methodology for land suitability classification and the term *Suitability* is used rather than Capability. According to the FAO Framework, "land suitability is the fitness of a given tract of land for a defined use" (FAO, 1976). As shown in Table 3.3 the Framework has four categories of decreasing generalisation: land suitability orders, classes, subclasses and units. Suitability orders indicate whether land is assessed as suitable (S) or not (N) for the use under consideration. Classes indicate the degree of suitability (up to five), for example, highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1) and permanently (N2). Subclasses indicate the type of limitations and are presented by lower case letters, for example S2m for suitable land with specific limitations of moisture availability. Land suitability units are subdivisions of subclasses for example, S2m-1, S2m-2, S3m-3...etc. They differ from each other in their production characteristics or in minor aspects of their management (often definable as differences in detail of their limitations) (FAO, 1976).

Table 3. 3 Structure of the suitability classification

Order	Categories Class	Subclass	Unit
Suitable	S1 S2 S3	S2m S2e S2 me etc	S2e-1 S2e-2 etc.
Not Suitable	N1 N2	N1y N1z Etc.	

Source: FAO (1976)

The basic concepts of the Framework include : land, land mapping units, major kinds of use, land utilisation type, land characteristics, land qualities, diagnostic criteria or diagnostic factors, land use requirements and land improvement. The FAO Framework is based upon six principles:

1. *"Land suitability is assessed and classified with respect to specified kinds of use.*
2. *Evaluation requires a comparison of the benefits obtained and inputs needed on different types of land.*
3. *A multidisciplinary approach is required.*
4. *Evaluation is made in terms relevant to the physical, economic and social context of the area concerned.*
5. *Suitability refers to use on a sustained basis.*
6. *Evaluation involves comparison of more than a single kind of use."*

(FAO, 1976, p.3).

This means that the requirements of the various land uses have to be established and then the actual characteristics of land mapping units have to be assessed as to how well they provide optimum conditions. The comparison of land mapping unit with land requirements is called "matching".

A distinction is made between *a major kind of land use* and *a land utilisation type*. The major kind of land use is a major subdivision of rural land use, such as rain-fed agriculture, irrigated agriculture, grassland, forestry or recreation while the land utilisation type is the kind of land use described or defined in greater detail.

It is worthwhile noting that the land utilisation type is described not only in terms of actual land uses or crops, but also with reference to such factors as the type of market orientation (subsistence or commercial production), capital intensity, labour intensity, technology employed, infrastructure requirements, the size and configuration of land holdings, land tenure and income level (FAO, 1976). The FAO method recommends that land units should be evaluated in terms of *land quality* (LQ). Land qualities may be expressed in a positive or negative manner for example, moisture availability or erosion resistance. Land qualities can sometimes be estimated or measured directly, but are frequently described by means of *land characteristics* (LC). To evaluate a land unit in terms of land qualities, *diagnostic criteria* are recognised. Critical values are associated with diagnostic criteria so that the suitability classes can be defined. An example of a land quality is "oxygen availability in the root zone" to demonstrate the nature of *diagnostic criteria*. In this case, soil drainage class, soil mottling or natural vegetation could be used as a diagnostic for assessing oxygen availability (FAO, 1976). Once relevant land qualities are selected and assessed, the next critical stage in land evaluation is to compare the requirements of land utilisation types with the land qualities of individual mapping units. The comparison of land use with land is the key process of land evaluation. It is the most important stage which brings together analyses of the land and land use data, as well as economic and social information. The fundamental principles of the Framework refer in particular to the necessity to compare specific alternative kinds of land use that should be economically viable and ecologically sustainable (van Diepen *et al*, 1991). It emphases in particular the importance of explicitly stating the intended land use and the level of management envisaged, and that land evaluation may be either on current suitability or, as for irrigation or drainage schemes, on potential suitability (Davidson, 2002).

There are some key points which distinguish the FAO Framework from previous land classification systems. Firstly, this Framework evaluates separately for each specific use and then combines and compares uses. Secondly, land is defined broadly and not only by soil characteristics. Finally, land should be evaluated physically and economically (Rossiter, 1999). These factors make the FAO approach a robust and flexible methodology. The FAO has published guidelines for land evaluation in: dry lands; irrigated agriculture; forestry; extensive grazing and steep lands (FAO, 1976; 1983; 1985; 1991).

In the FAO guidelines for irrigated agriculture (1985) the basic concept advocated by the FAO Framework (FAO, 1976), upon which the method is based, is shown to be complementary to the principles of the USBR classification which is specifically for irrigation. Two subdivisions of potential suitability are introduced in this method; these are comparable, but not identical to the USBR's "arable" and "irrigable" land and are as follows:

<u>Provisionally-irrigable land</u>: This is land that is classified provisionally, on the assumption that water can be supplied to it, but in the absence of full knowledge about water supply or the project land development cost. Net farm income is a useful measure of suitability of "provisionally-irrigable land". Net farm income is defined as the value obtained by subtracting both variable and fixed costs from the gross value of production.

Irrigable land: This is land that is suitable for irrigation under a "provisionally-irrigable" classification, that can receive water, and that has been classified according to an economic evaluation of its suitability for specified LUTs, this takes into account the water supply, the incremental area-specific development cost, the common project costs and the benefits. Net irrigation incremental benefit (NIIB) may be used to measure the suitability of "irrigable land" (FAO, 1985) . NIIB "is a measure of the potential increase in productivity of a unit area of land developed under a project plan, expressed in economic terms". As noted, FAO guidelines for irrigated agriculture are based on an economic basis to evaluate the land for irrigation taking into account the costs and the benefits of the project plan.

3-2-5 Recent Advances in Land Evaluation

3-2-5-1 GIS / Fuzzy Algebra

The application of GIS to land evaluation is ideal given the focus on the input, management, processing, and display of spatially referenced datasets. The use of GIS has become standard practice in land evaluation for over 10 years.

There is a considerable literature demonstrating the use of GIS in land evaluation. Fernandez *et al*. (1993) provided an overview on the application of GIS to rural planning and management. East and Wood (1998) described the use of LANDCRE GIS as a means of providing an integrated approach in Australia for identification and analysis of spatial relationships between the National Landcare Programme (NLP), land resource condition and land use practices. Data availability and quality are crucial to the development of such system. East and Wood (1998) concluded that it might be a long time before data consistently high quality and at required scales become available.

Davidson *et al*. (1994) used a GIS to evaluate land for wide range of agriculture crops in Viotia, Greece. As another example of using GIS, Makhdoum (1993) described a computerised land evaluation methodology for locating a new industrial-urban development site in Iran.

Boolean logic has been used in GIS to determine if particular mapping units meet defined requirements for proposed land use or cropping. There are some problems associated with this approach. The methodology is based on assumption that variations in land or soil properties occur in neat steps corresponding to land mapping units. In reality, spatial variability in individual properties may not correlate with mapping units. In addition, variability in properties within mapping units is the norm and thus there is always some uncertainty in stating that mapping units have values for particular properties above or below certain threshold values (Davidson, 2002). As a result, there has been much interest in recent years in the application of fuzzy set algebra to land evaluation.

Given these issues, Van Ranst *et al*. (1996) argued that a fuzzy logic approach to land suitability assessment was much more satisfactory than methods based on the principle of limiting factors or some parametric system. Groenemans *et al*. (1997) also supported the use of fuzzy logic in land evaluation, but they stressed the problems associated with assigning weights to particular attributes or land qualities. The results are as good as the input data. Regardless of the logic which can be used, the first issue to be tackled is the data availability. In addition, a fuzzy logic approach is very dependent upon the determination of membership functions, a topic in land evaluation requiring substantial research. In the Libyan context of this research, data availability represents a major limiting factor on the adoption of a fuzzy-set approach to the land suitability modelling. Without suitable quantities and quality of datasets underpinning the modelling, the traditional limiting factors approach adopted by the FAO framework serve the requirements the best. Equally, there is a need for substantially more research in the Libyan context to establish the membership functions applicable to the crop-model requirements. This could be seen as a subject for future research.

3-2-5-2 Soil Quality Monitoring and Assessment

The concept of soil quality and its assessment is causing considerable controversy in soil science, as reviewed by Davidson (2000). An expanded definition of soil quality is given by Karlen *et al*. (1997). Sojka and Upchurch (1999) provided a robust assessment of the soil quality concept which they state has not been subject to comprehensive critical examination in terms of fundamental scientific principals. They do not argue against the importance of improving soil assessment procedures as a means of promoting sustainable use of soils. However, they argue that soil quality assessment is necessarily subjective, outcome driven, value laden and dependent upon particular contexts. For the purposes of this research, it is argued that the issues addressed by soil indicators are in fact broadly commensurate with the land characteristics as espoused in the FAO framework.

3-3 Discussion

There are many land evaluation techniques which have been developed to assess land for different land uses. This chapter has outlined the most widely applied methods in land evaluation such as the USDA method and its adaptations, the FAO Framework for land evaluation, the USBR method and the Storie Index Rating. In order to select or adapt an evaluation method for agricultural development in Libya, a comparison has to be made between these different techniques in the Libyan context. Before this comparison takes place, it is essential to distinguish between the terms "suitability" and "capability". Suitability and capability are often confused or even regarded as synonymous. Suitability is a single clearly defined, reasonably homogenous purpose or practice e.g. barley production, whereas capability in related to a broader use such as agriculture or urban development (McRae and Burnham, 1981).

Within this research, land suitability is seen as the fitness of a given area of land for defined use, whereas land capability assesses the degree of limitation to land use or potential imposed by land characteristics on the basis of permanent properties. Whilst other interpretations do exist in the literature, these definitions are seen as being the closest to the investigator's viewpoint.

Land capability classification (principally the USDA method) attempts to provide a single-scale grade of land from "best" to "worst"; it assumes that arable use is the most desirable and it is biased towards the consideration of soil conservation and limitations (negative land features). It was originally developed to assist farm planning for land layouts, crop rotations and conservation practices (van Diepen, 1991).

The USDA method answers the following questions: how much good arable land is there and where is it; and where are there problems of erosion, drainage, salinity, etc. The main disadvantage of the USDA method is the failure to classify the land adequately for uses other than arable (Dent and Young 1981). Capability classification cannot distinguish between "elite" soils and "unique" soils. The first being soils which have no limitations for general arable use and the latter being soils which are particularly suitable for certain specific kinds of land use even though they may have limitations for the typical arable use of the area. Unique soils require specialised management, but under such management they can sometimes be more profitable than soils that would be placed in higher land capability classes (Dent and Young, 1981).

Land suitability classification (FAO Framework) is the process of assessing the suitability of land for specific kinds of use. The Framework (FAO, 1976) proposes that land evaluation should be able to answer questions such as: how land is currently managed and what will happen if present practices remain unchanged? What improvements can be made to management practise, within the present use? What other uses of land are physically possible and economically and socially relevant? Which other uses offer possibilities of sustained production or other benefits? What adverse effects, physical, economic or social, are associated with each use? What recurrent inputs are necessary to bring about the desired production and minimise the adverse effects? What are the benefits of each form of land use?

The intention is that the FAO Framework can be applied in any environmental situation and at any scale. The land mapping units are evaluated with reference on the land utilisation types which also incorporate social, economic and technological descriptions. In contrast land capability schemes have as their main focus the grading of land according to the degree of limitations imposed to one or more land uses. Assumptions are made about the aspects and level of management, farming structure and location. An example of the comparison between land capability classification and the FAO framework was provided by Kanyanda (1988). He provided an interesting report on the experience in Zimbabwe when he compared the land capability system there with the FAO Framework. The capability system was evolved from the USDA calssification and has as its main objectives the identification of the most intensive land uses which do not result in erosion as well as indicating land use limitations. The Zimbabwe capability scheme grades the land from Classes I to VIII and is thus a simple practical system, easy both to use and apply. Davidson (1992) stated that the main disadvantages of the Zimbabwe capability scheme are its limited nature, lack of flexibility, overemphasis on limitations rather than on potentials, and its design for a commercial farming system. Thus according to Kanyanda (1988) difficulties arise in trying to apply the system to the peasant areas.

Kanyanda contrasts the objectives and the assumptions of the Zimbabwe Land Capability scheme with those of the FAO Framework (Table 3.4).

The land capability classification philosophy is built on an evaluation of the constant land characteristics; assuming that arable is the most desirable use and not taking the crop requirement into account. If the capability approach is implemented, there will not be a separate evaluation for different crops and in addition, there is no differentiation between management levels or techniques.

Table 3. 4 Comparison of the Zimbabwe land capability system with FAO Framework

Zimbabwe land capability	FAO Guidelines
Refers to a range of uses (broad agricultural base)	Refer to tightly defined use or practice
Limited –adopted for commercial areas especially for conservation purposes	Flexible
Applicable for farm planning (scale larger than 1:15,000)	Applicable at all levels of scale from national to farm planning
Employs the use of land characteristics which remain more or less constant over time	Employ the use land qualities with their dynamic nature
Can be executed by a single worker e.g. agricultural officer	Calls for a multi-disciplinary approach (pedologist, agronomist, economist, etc)
More concern for conservation of land resources and less concern for people	Takes into account land and socio-economic setting
A physical classification with no proper economic considerations	Allows for an economic and social analysis
Not a productivity rating for specific crops	Rating for specific crops and farming systems

Source: Davidson (1992)

Davidson (2002) states that the USDA land capability can not be regarded as complete land evaluation technique. The assessment of capability classes shows an obvious lack of precise quantitative criteria. For example, phrases such as 'gentle slope', 'moderate susceptibility to wind or water erosion' or 'less than ideal soil depth' have no clear definition and therefore can be interpreted differently. Any effort made to fix rigid limiting values relevant to a variety of environments will encounter major obstacles. For example, the significance of soil texture will vary according to the climate regime, the types of crops and land use (Davidson, 2002).

An other well-known land classification system is the USBR system which is a land classification for irrigated land. As discussed section in 3-2-3, the criterion for suitability in this system is the payment capacity of land e.g. the money available for a farmer to pay water charges. This criterion applies to the financial situation of individual farmers and is a measure of overall land productivity. Within this system, lands are classified into classes that reflect the capacity of the land to support adequately a farm family and pay the water charges (FAO, 1985). There are three disadvantages of using this methodology: firstly, the method does not take into account the suitability of crops for specific land and it categorises land only in terms suitability for irrigation. Secondly, the bio-physical relationships between crop and land mapping unit (LMU) are not apparent and some qualities of land which affect crop production such as climate are ignored. Finally, if the decision to develop an irrigation project has been taken on political or national economic grounds, the question of whether it is worthwhile is redundant. The evaluation producer can then start by grouping soils on the basis of the physical criteria only (van Diepen *et.al,* 1991). This is also true for the FAO (1985) method which is based on economic principles. The decision of the irrigation project in Libya was taken on the basis of the national policy whose aims are to be self–sufficient and have food security. Therefore, the USBR and FAO (1985) do not fulfil the selection criteria of this research.

The Storie Index Rating was an early attempt at quantitative land evaluation. It can be appreciated that there is considerable value in being able to produce a number, ranging from 1 to 100, which expresses land suitability for one or more specific crops. The system has been widely applied, for example Leamy (1973) described how it has been used in New Zealand to aid farm valuation assessment and Lal (1989) applied a modified Storie Index to rate the productivity of sixty-four benchmark soils in India. In this Indian study the rating was on the basis of four factors; characteristics of the physical profile, surface texture, slope and a group of other factors such as drainage, nutrient status and erosion. Mahmoud (1995) applied a modified productivity rating in Libya. In the Libyan study, eleven soil properties were taken into account to produce an overall rating. The productivity rating focuses on soil properties and ignores land qualities such as climate. This productivity rating could mislead agricultural planning because it does not take into account crop requirements which are a vital part of agricultural production.

While such methods (parametric methods) can give useful and reproducible results in specific localised areas and circumstances, they are not recommended for universal application, since wildly inaccurate predictions can arise when a productivity index is used outside the area within which it was developed. Furthermore, there are three main drawbacks to parametric systems: firstly, they are subjective. Although they appear objective through the use of standard procedures and numerical values, rating systems involve subjective processes such as the selection of properties to be used and the form of the equation. Secondly, there is a possibility of bias, because it is difficult to decide what parameters to choose for the land characteristics which are the determinant of the final index. Thirdly, the rating obtained for an area is not immediately translatable into management terms, since it gives no direct indication of the nature of severity of individual land deficiencies requiring specific management practices (McRae and Burnham, 1981). In addition, particular attention must be paid to the interpretation of the values obtained if the formula is a multiplicative one. In multiplicative systems the low values of unfavourable properties automatically reduce the final rating, and in the extreme case where an individual value is zero, the final rating is zero.

Nearly all the land evaluation methods reviewed in this chapter, except the FAO Framework have generalised approaches where local conditions are ignored. Also decisions on the use of land are not considered. In the FAO Framework, land suitability is determined separately for each land utilisation type (LUT), which is a specific way of using land area, with specific management methods and levels. A key concept of the FAO method is the concept of land use requirement (LUR). These are the general conditions of the land necessary for successful and sustained use i.e. what a particular use requires from the land. While the LUT is defined by a set of LURs, the land offers land qualities (LQs). LQs are measured as classified factor ratings, and express the ability of land to fulfil specific requirements for a specific land use (Rossiter, 1990).

In the FAO method "the comparison of land use with land" (matching) is an important process. This is the stage where land, land use, economic and social information are brought together. Matching is important in order to estimate or predict land use performance. This is very much the requirement in Libya, where the land suitability for certain crops is required to meet the national policy.

The FAO method has been fully tested, applied, and proven in developing countries such as Zimbabwe, Jordan, Tanzania, Brazil, and Kenya (Kanyanda 1988; Nagowi & Stocking, 1989; Wandahwa & van Ranset, 1995; Hatten and Taimeh, 1998). For example, in Jordan, the FAO method was used in the sustainable development of the marginal rain-fed zones (100-200 mm mean annual rainfall) and provided a basis for the optimal use of region's land and water resources. The methodology used followed the method outlined by FAO

(1976). With this Framework, land was evaluated for a number of potentially competing land uses and management systems (Hatten and Taimeh, 1998). The Jordanian example of land evaluation supports the selection of the FAO Framework in Libya because of the similarity of the physical conditions between Libya and Jordan. Wandahwa and van Ranset (1995) used the FAO method in Kenya to select the best land for pyrethrum and determination of the production limiting-factors were devised through a qualitative process of matching land characteristics with crop requirements using a model built in the Automated Land Evaluation System (ALES). Climatic, soil, and landform requirements for pyrethrum cultivation were provided and used in the evaluation, and land suitability maps were presented. Nagowi and Stocking (1989) used the FAO method as the basis of land suitability for coconuts in the Coastal Belt of Tanzania. Land suitability classes and maps were presented. The aim of that work was to provide the planner and decision makers with the results which are needed to target scarce resources to optimal areas and to design viable farm units and farming systems for local physical, social, and economic conditions. It was suggested that Tanzanian planners and many others in developing countries have accepted the techniques and are applying them to other parts of the country at a variety of scales and level of detail and for number of specific purposes.

3- 4 Conclusion

In the light of this review, the FAO framework has been selected to conduct the land suitability for the cultivated crops in Libya. The selection of the FAO approach in this research was based on the following rationale:

1. Land resources inventories are placed at the centre of the evaluation process in the FAO method. This is very important because it requires a comprehensive integration and compilation of different data in a natural resources database.
2. The FAO framework considers it necessary to make a description of all land utilisation types relevant to the area. This includes all the characteristics of the production system and social context that influence suitability. This description is very important for the completion of the socio-economic analysis aspect of Libyan agriculture projects, which will follow the physical assessment in order to produce suitable land use planning recommendations.
3. It enables the evaluator to choose either qualitative or quantitative evaluation. This is important because data may not be available to implement a quantitative evaluation, especially at the regional level.
4. The matching process in this approach has an iterative nature; presenting the evaluation results to an expert for field validation reveals whether the results are in agreement with what is expected of the land. This is vitally important since the ratings of different land qualities are mainly based on experience and judgement in the project area. This is considered a quality control measure for the whole land evaluation process.

The following chapters (Four, Five, and Six) describe the study area; discuss the land utilisation types, land use requirements; and how the FAO framework has been applied in Libya.

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4

The Study area and land Utilisation types

This Chapter provides background of the study area to aid the development of land evaluation framework and identifies land use requirement, land qualities, and land characteristics of the Libyan case. In addition, it discusses data requirements, availability, and interpretation for the study area.

4-1 The Study Area

4-1-1 Location of the study area

The study area has been selected on the basis that it is one and the first areas that will receive transferred water from the Sothern aquifers. In addition, it is the most complete data available compared with the other regions.

The study area is located in the strip of the coastal territory and Jabal Akhdar Upland bounded by the following coordinate's lat 31° 30′ – 33° 00′ N; long 19° 50′ - 22° 45′E (Figure 4-1).

This area of the country is known as North East and includes the Benghazi region and the Jabal Akhdar highlands (Figure 2.1). Upon the completion of the GMRP, 155,000 ha in the north east of Libya will be irrigated. The reclamation and development of some 38,000 ha in Benghazi region served by the Ajdabiya-Benghazi line from the GMRP will also be undertaken.

This study considers the Benghazi region in order to develop a land suitability classification in this region as the first area to be irrigated with the GMRP.

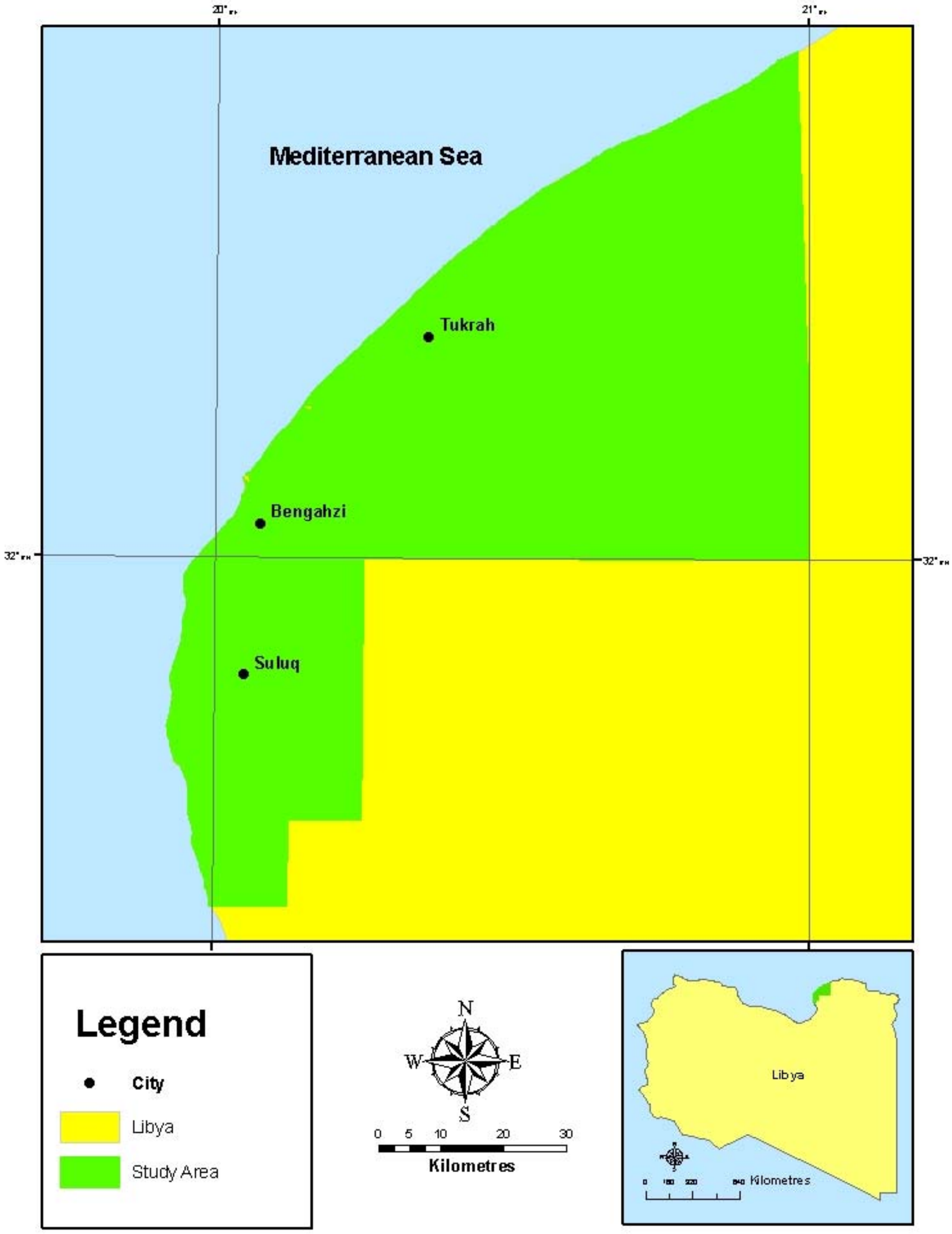


Figure 4. 1 The location of the study area

4-1-2 Data Requirements, Availability and Interpretation

Land evaluation requires the availability of appropriate data. Therefore, the available data for the study area have been reviewed. Essential information on soils, climate, and crops from the Benghazi area was collected during a visit to the region and through co-operation with institutions and authorities in Tripoli. The data have been used for establishing the land suitability and production potential of soils.

As with most land evaluation applications, climate, soil and crop information are the dominant source of data for establishing physical suitablities for various crops. The soil information in the form of detailed soil maps can be used as a basis for regional land evaluation studies, if there are no significant variations in climatic conditions that could affect the suitablities of crops. Detailed studies revealing the characteristics of soils, climate and crops will hold the key to a successful land evaluation application.

4-1-3 Soil Information

The soils in the north east and north west of Libya were investigated by Selkhozpromexport (1980), Agriculture Research Centre (ARC), Al-Fateh University and the Ministry of Agriculture in the 1980s. A detailed report was published (Selkhozpromexport, 1980; Mahmoud, 1995). The spatial soil information available to this reserch was limited to 1:250,000 soil maps on soil subtypes level. The data which were available to this research are, topsoil texture, soil depth, stoniness, salinity and alkalinity, $CaCO_3$, pH, organic matter. All of the above parameters directly or indirectly can affect the production of crops, and therefore physical suitability of a soil for crop production.

4-1-3-1 Soil mapping and classification

Soil was classified using the taxonomy of the Soviet pedology. Classes and subclasses are singled out on the basis of classification of the structure of soil in the tropics and the subtropics (Zonn, 1974).The classification distinguishes 2 soil classes, 6 subclasses and 11 soil types (including 31 soil subtypes). The scheme of soils division into classes, types and sub-types are given in Table 4-1, and the definitions of Soviet terminology used in this chapter is given in Box 4.1. A map of the soil types in the study area is presented in Figure 4.2 and a map of the soil sub types is shown in Figure 4.3. In addition, a brief description of the soil sub types in the study is given in Appendix B (B1.2).

Box 4. 1 Soil terminology used in the Soviet Classification

Class: Taxa are defined according to broad temperature belts and designed as global classification
Subclasses: Automorphic (approximately equal to "Zonal"), hydromorphic, semi-hydromorphic and alluvial are the subclasses more commonly recognised
Type: This is the level most commonly used for broad regional comparisons and generalisations
Sub-type: This category is composed of taxa within the types differing qualitatively in expression of one of the soil formation processes and /or intensity with which they reflect the main pedogenic process of the type.
Genera : Taxa are defined according to properties of the parent material as reflected in texture and composition, or according to special dominating effects of chemical composition of the ground water or according to some relict or fossil features (Selkhozpromexport, 1980).

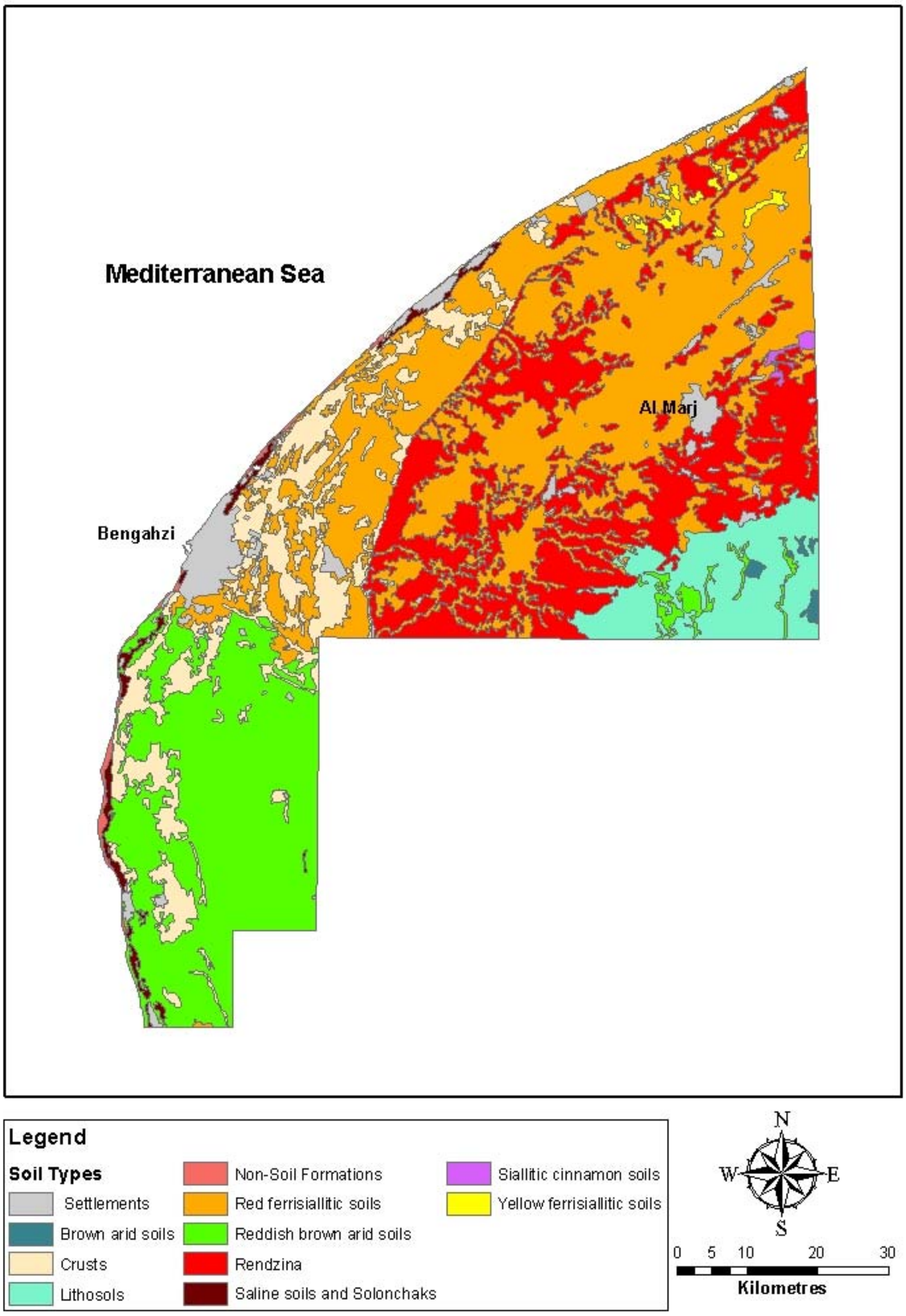


Figure 4. 2 Soil types in the Study area

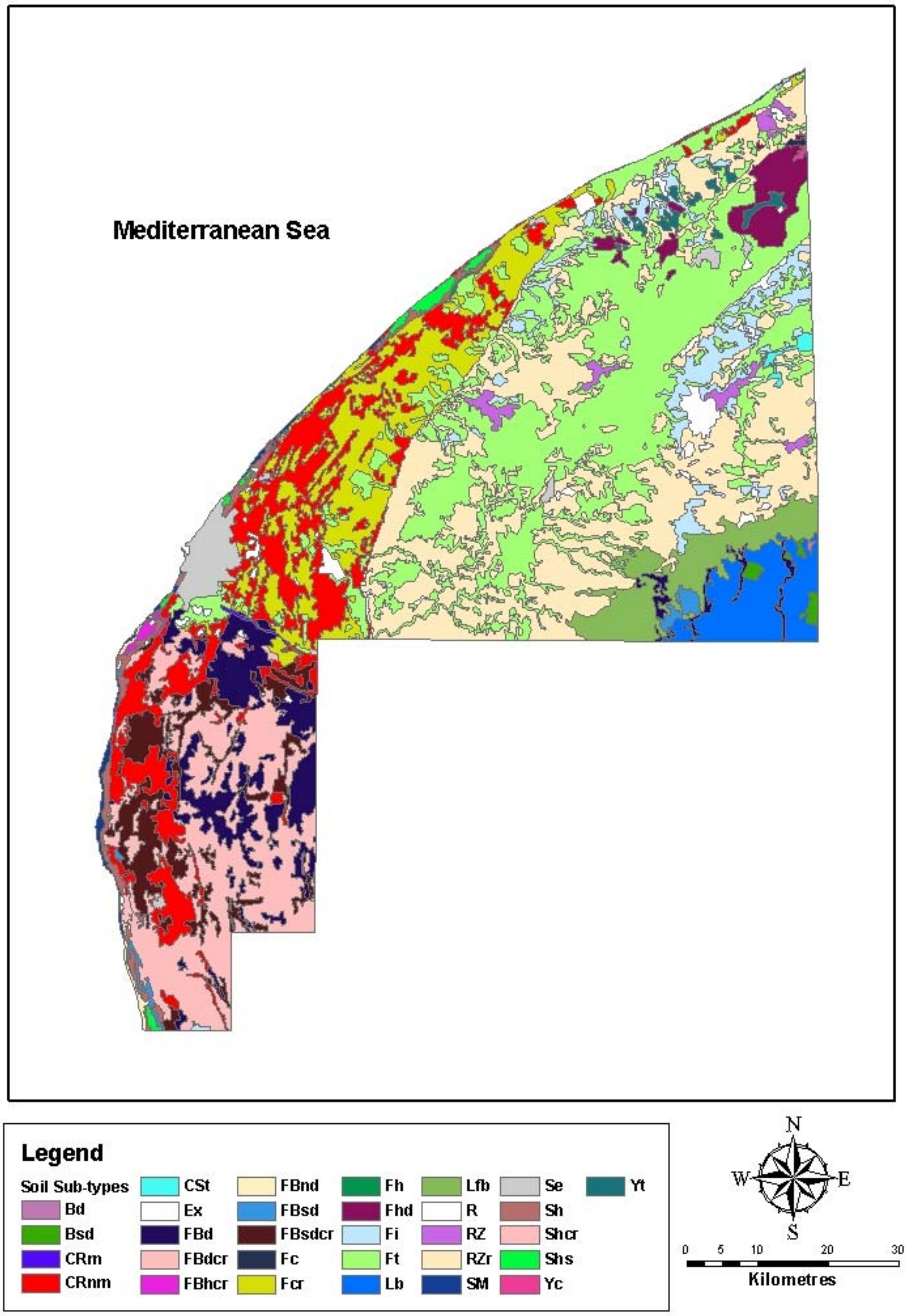


Figure 4. 3 Soil Sub-types in the study area (see Table 4.1 for sub-types codes)

Table 4. 1 Soil Classification in the North East of Libya

Soil types	Soil Subtypes	Code
Brown arid soils	Brown arid differentiated soils	Bd
	Brown arid slightly differentiated soils	Bsd
Crusts	Monolithic crusts	CRm
	Non - monolithic crusts	CRnm
Siallitic cinnamon soils	Siallitic cinnamon compact soils	CScp
	Siallitic cinnamon typical soils	CSt
Reddish brown arid soils	Reddish brown arid differentiated soils	FBd
	Reddish brown arid differentiated crust soils	FBdcr
	Reddish brown arid hydromorphic crust soils	FBhcr
	Reddish brown arid non - differentiated soils	FBnd
	Reddish brown arid slightly differentiated soils	FBsd
	Reddish brown slightly differentiated crust soils	FBsdcr
Red ferrisiallitic soils	Red ferrisiallitic concretionary soils	Fc
	Red ferrisiallitic crust soils	Fcr
	Red ferrisiallitic hydromorphic soils	Fh
	Red ferrisiallitic hydrated soils	Fhd
	Red ferrisiallitic soils of a truncated profile	Fi
	Red ferrisiallitic typical soils	Ft
Lithosols	Brown lithosoils	Lb
	Cinnamonic lithosoils	Lcs
	Reddish brown lithosoils	Ltb
Rendzina	Dark rendzinas	RZ
	Red rendzinas	RZr
Saline soils and Solonchaks	Automorphic solonchaks	Sa
	Hydromorphic solonchaks	Sh
	Hydromorphic crust solonchaks	SHcr
	Hydromorphic sebkha solonchaks	SHs
Non-Soil Formations	Maritime sands	SM
Yellow ferrisiallitic soils	Yellow ferrisiallitic concretionary soils	Yc
	Yellow ferrisiallitic typical soils	Yt

4-1-3-2 Physical Soil Characteristics

The physical properties affect the irrigation conditions as well as available water capacity for crops. The full physical soil properties data are given in Appendix B2.

The particle size analysis using USDA standards showed that the texture of soils in the study area range from clay to sand. The textures of the soil sub-types include clay, clay loam, loam, sandy clay loam and sand. Figure 4. 4 show the soil textural distribution for the soil sub-types in the study area.

Soil depth in the study area varies within the soil sub-types. The highest depth was found in yellow ferrisiallitic typical soils and the lowest values were obtained in brown lithosols (Ltb). Figure 2.14 shows soil depth for the soil sub-types in the study area.

For the infiltration rate of the soil in the study area, the most rapid infiltration rate was 17.5 cm/ h measured in siallitic cinnamon soils (CScp) and the lowest in brown arid soils (Bd) with 1.2 cm/ h. The highest values of unsaturated hydraulic conductivity found in siallitic cinnamon typical soils (Cst) and the lowest values obtained in brown lithosols (Lb).

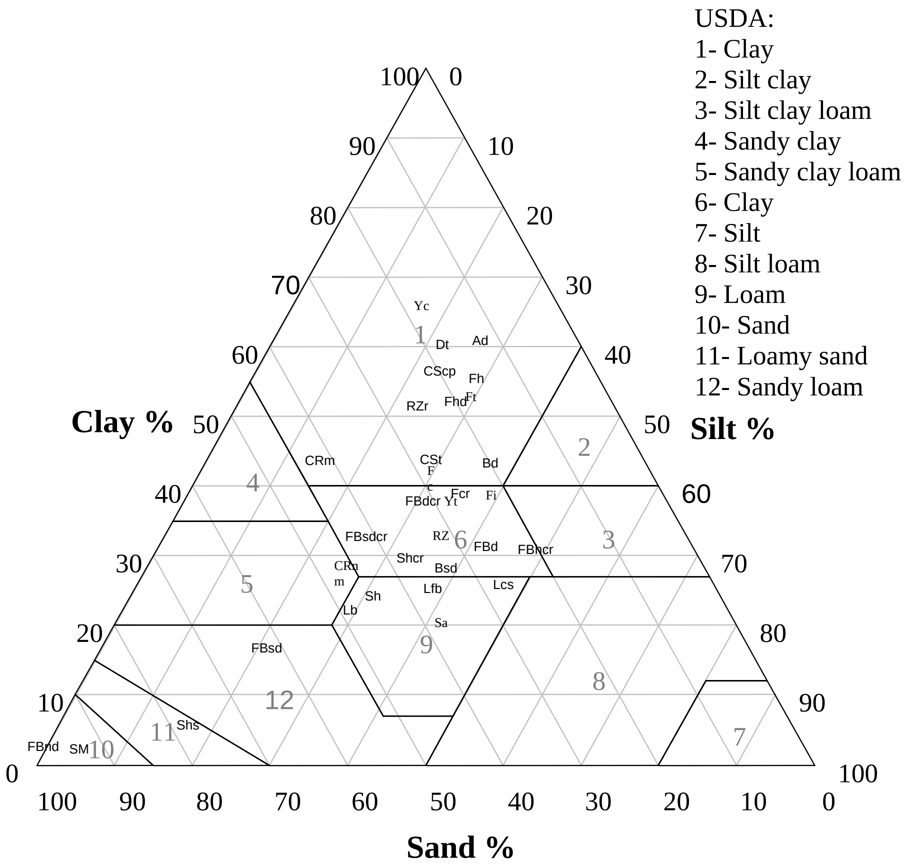


Figure 4. 4 Soil textural distribution in the study area (see Table 4.1 for soil sub-types code)

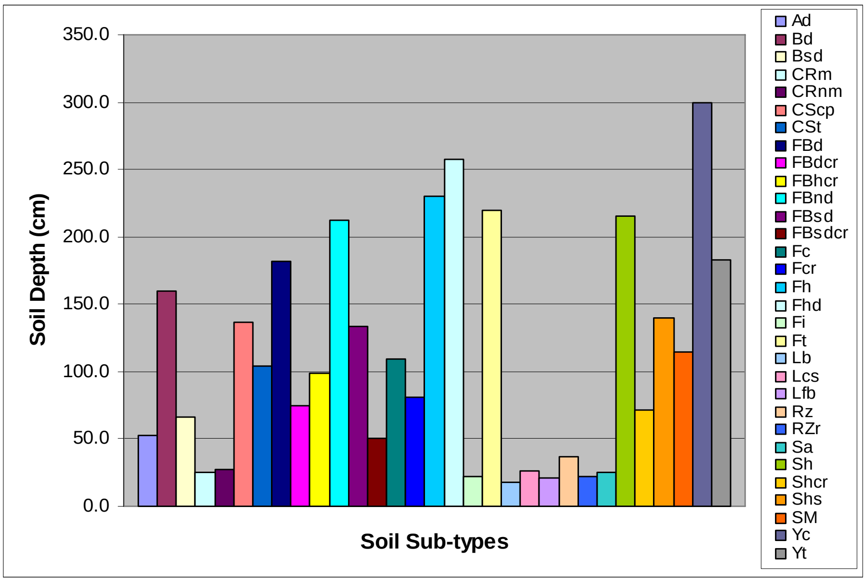


Figure 4. 5 Soil depth for the soil sub-types in the study area

4-1-3-3 Chemical Soil Characteristics

The soils of the study area are low in organic matter. The highest value was obtained in the rendzinas (Rz) which had approximately 4 %. The majority of soils had less than 1.5 % organic matter. The lowest value of organic matter was found in the reddish brown arid non - differentiated soils (FBnd) which had 0.32 %.

The carbonate content of the soils was considered to be generally high: the lowest value were found in yellow ferrisiallitic typical soils (Yt), red ferrisiallitic typical soils (Fi), red ferrisiallitic crust soils (Fc), which had less than 1 %. The highest carbonate content values were found to be more than 30 % and they were obtained from brown lithosols (Lb) and reddish brown arid non - differentiated soils (FBnd).

4-1-4 Climatic Information

The study area is situated in a Mediterranean type climate, in the belt of subtropical alternate atmospheric circulation. In the summer the climate is determined by a stable high pressure zone situated over the Mediterranean Sea, i.e., by the Azores maximum spur with descending tropical air currents. In the autumn-winter-spring period, climate conditions are determined by the cyclonic activity of the ascending air masses in the temperate latitude zone. The mean air temperature in winter is two or three times lower than the summer. The amount of total rainfall precipitations from October to March is 85-90 per cent of the annual precipitation, its maximum evidently being in winter (Figure 4.7). The contrast in seasonal climatic indices increases due to two factors: orographics (Atlas Mountains), and baric (the high pressure zone in summer).

The climatic conditions in the study area are unstable and depend on the distance from the sea and the altitude of the territory. Further inland, the mean annual air temperature increases, while the precipitation amount decreases. With an increase of absolute elevation in the Jabal Akhdar Upland, the mean annual air temperature drops abruptly and the amount of precipitation increases. The orographic temperature gradient equals 3.8°C, that of precipitation being 345.1 mm. Thus, according to the seasonal changes of the characteristic climatic conditions of a Mediterranean climate type, two periods can be distinguished in the region:

1. Xerothermal, hot and dry with the temperature in May-October exceeding 20° C and the amount of precipitation varying in April-September from 5.4 mm to 42.9 mm (the meteorological stations of Saluq and Shahhat);
2. Mesothermal, warm and moderately humid with the temperature in November-April being from 10°C to 20°C and the precipitation in October-

March from 148.5 to 524 mm (the meteorological stations of Saluq and Shahhat).

On the other hand, the softening and smoothing influence of the Mediterranean Sea combined with more continental and arid climatic conditions moving from the west and east in the locality of Benghazi and the complex orography of the terrain to the south , also result in sharp fluctuations of the climatic indices

1. Sub-humid characteristics of the upper step of the Jabal Akhdar upland;
2. Semi-arid, typical of the lower step of the upland and adjoining area of the littoral plain. Figures 4.6, 4.7 and Table 4.2 show the temperature and rainfall in Benghazi area.

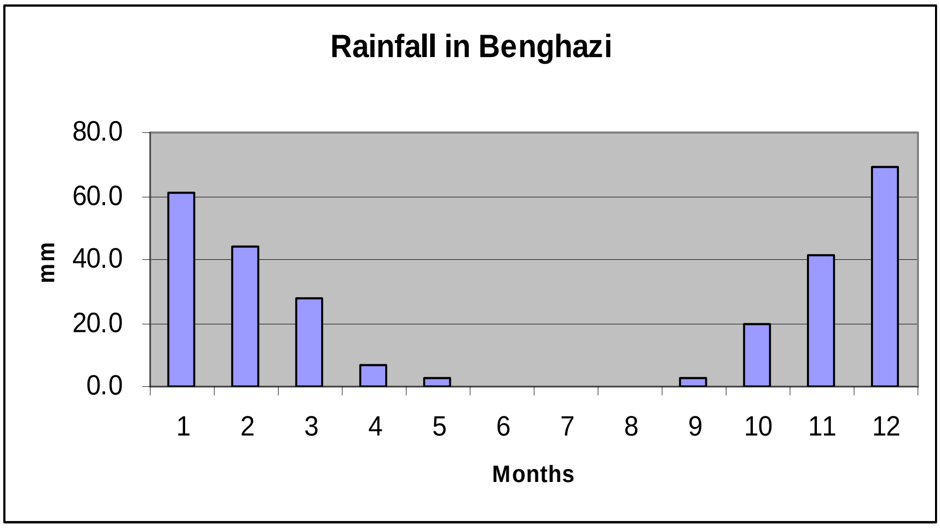


Figure 4. 6 Monthly Average Rainfall from Benghazi (mm) Years from 1973-2001.

Source: Benina Meteorological Report

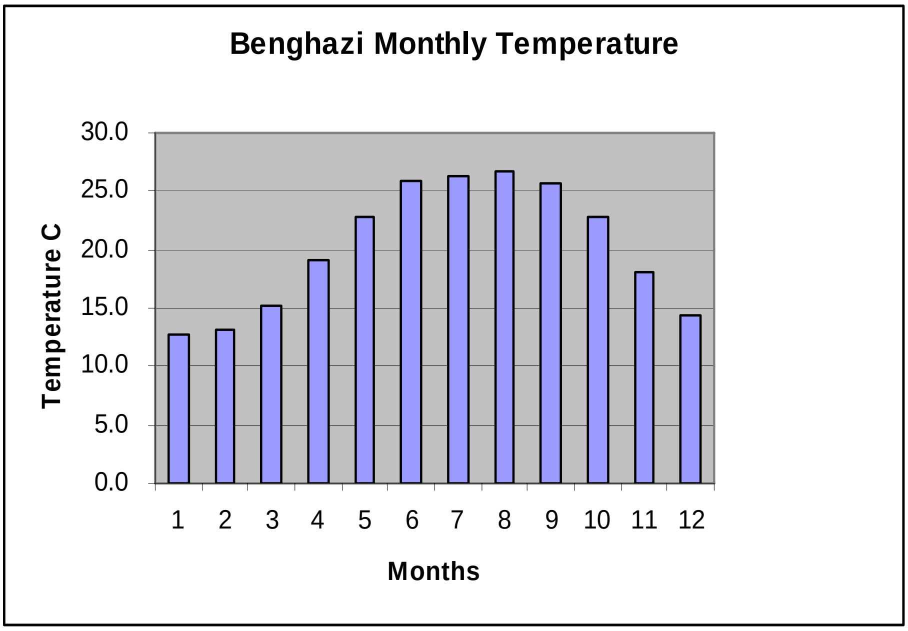


Figure 4. 7 Benghazi Mean Monthly Temperature from Benina Meteorological Stations Years from 1973-2001 (Source: Benina Meteorological Report)

Table 4. 2 Benghazi Monthly Temperatures Years from 1973-2001

Months	Mean Monthly Temp °C	Mean Monthly Maximum Temp °C	Mean Monthly Minimum Temp °C
January	12.7	16.4	8.9
February	13.2	17.3	9.1
March	15.3	20.0	10.5
April	19.0	24.4	13.6
May	22.8	28.5	17.1
June	25.8	31.5	20.1
July	26.4	31.4	21.3
August	26.8	31.7	21.8
September	25.8	30.8	20.6
October	22.9	27.7	17.9
November	18.1	22.3	13.8
December	14.4	18.1	10.6

Source: Benina Meteorological Report

4-1-5 Geology

The eastern zone is situated on the northern periphery of the ancient African platform (ASGA-UNESCO, 1968). During the Paleozoic period northern Libya, as well as the whole African continent, was part of the vast Gondwana super continent (Khainm, 1971). The fragmentation of the Gondwana super- continent that began in the Permian period led to the development of the Tethys Ocean, of which the Mediterranean Sea is a surviving remnant. According to Kiltzsch (1971), the northern part of Cyrenaica was a constituent of the Tethys geosynclines, having adjoined to the platform in the course of the pine orogenesis.

The sub-surface rock stratigraphic column, according to Burollet, 1960, 1963; Klitzsch, (1971) has the following composition (from deepest levels upwards):

- Pre-Cambrian basis composed of highly metamorphosed granite, gneisses, quartzites and crystalline shale. In the anticline core its bedding is the closest to the surface, the depth being over 1.0 km;
- Cambrian Devonian quartzite, feldspathites, quartzite sandstones, mudstones, micaceous batts;
- Permain marine sediments (limestones, sandstones) in the northern part of Cyernaica, which was part of Tethys;
- Continental Mesozoic rocks or “Nubian sandstones”.

Figure 4.8 and Table 4.3 show the geological composition in the study area

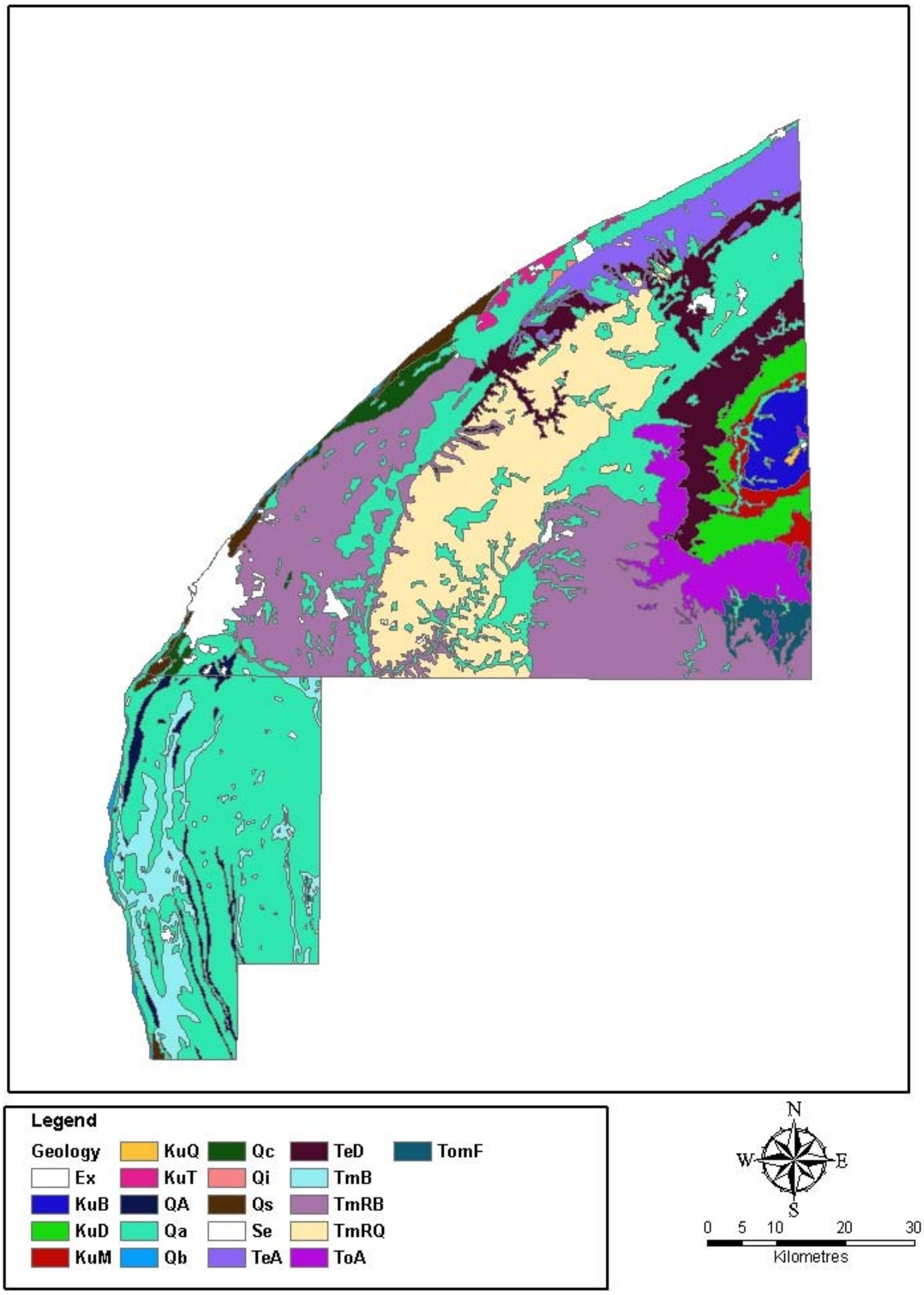


Figure 4. 8 Geology of the North- East of Libya

Table 4. 3 Geology of the study area

Code	Geology Type	Description
Ex	Exclusion	
KuB	Al Baniyah Formation	Limestone, Dolomitic Limestone, Marl
KuD	Wadi Dukhan Formation	Dolomite to Dolomitic limestone
KuM	Al Majahir Formation	Limestone, Dolomitic limestone to Dolomite, Marly limestone, marl
KuQ	Oasr al Abid Formation	Marl, calcareous clay
KuT	Tukrah Formation	Limestone, Limestone with chert nodules
Qa	Alluvial sediments	Loam, slty, gravel, Cemented gravel
QA	Agedabia Formation	calcarenite
Qb	Beach Sand	Calcareous sand, Sandy gravel
Qc	Calcarenite	Calcarenite, siltstone, clay
Qcs	Coastal sediments	Calcarenite, Beach sand, Salty clay, silt, sand
Qd	Eolian deposits	Sand dunes and sheets
Qg	Conglomerate	Cemented gravels
Qi	Landslide	
Qs	Sebkha sediments	Salt, salty clay, silt, clayey sand
Se	Settlements	Towns, Villages
TeA	Apollonia Formation	Limestone, partly bituminous, marly Limestone, siliceous limestone, chert nodules
TeD	Darnah Formation	Limestone, nummulitic limestone
TmB	Benghazi Formation	Limestone, fossiliferous limestone, dolomitic Limestone, oolitic limestone, calcareous clay
TmM	Msus Formation	Limestone, fossiliferous limestone, dolomitic Limestone, oolitic limestone, gypsum
TmRB	Ar Rajmah Formation-Benghazi Member	Limestone, dolomitic limestone, Fossiliferous Limestone, algal limestone, calcareous clay
TmRQ	Ar Rajmah Formation-Wadi al Qattara	Limestone, olitic limestone, Calcarenite, clay, gypsum
TmS	Al Sceleidima Formation	sand, calcareous sand, clay, gypsum, limestone
ToA	Al Abraq Formation	calcarenite, limestone to dolomite, marl
ToB	Al Bayda Formation	Limestone, Fossiliferous limestone, marl; including Shahhat Marl and Algal Limestone Members
TomF	Al Fa idiyah Formation	Limestone, Marly Limstone, Calcareous clay

Source: (Selkhozpromexport, 1980; Pallas, 1980)

4-2 FAO Framework for land evaluation

The FAO Framework for land evaluation (FAO, 1976) has been selected as the method for land evaluation within the Libyan case study. The rationale governing the selection of the FAO approach has been critically assessed in Chapter Three.

The FAO Framework (1976) is not a classification scheme, instead it is a set of methodological guidelines suited for implementation in land evaluation projects and at any scale. In the framework, land mapping units are assessed with reference to defined land utilisation types. These land utilisation types include social, economic, and technological descriptions (Davidson, 1992).

The principles of the FAO Framework (1976) specify that land should be assessed with respect to its suitability for a range of alternate land uses based on several criteria, in particular:

- specific land uses and the requirements of these land uses;
- a comparative multi-disciplinary analysis of inputs vs. benefits;
- the physical, economic, social and political context of the area concerned;
- potential environmental impacts and land use sustainability.

The FAO Framework recognises four main kinds of suitability classification; whether it is qualitative or quantitative, and whether the assessment is for current or potential suitability (FAO, 1976). Qualitative classification describes relative suitability in qualitative terms only, without any precise calculation of costs and return on investment. The quantitative classification defined the distinctions between classes in common numerical terms, and which permit objective comparison between classes relating to different kinds of land use.

There are two approaches that can be adopted to carry out the land evaluation: the two-stage approach and the parallel approach. The first is mainly concerned with qualitative land evaluation, followed by economic and social analysis (although not always necessarily). The second approach is one in which analysis of the relationships between land and land use proceeds concurrently with the economic and social analysis (FAO, 1976).

A partial first approach was selected for this study i.e. a qualitative land evaluation of the physical conditions. The decision was taken on the basis of detailed assessment of the Libyan context. The results of this assessment indicated that there are currently two main reasons why it is not possible to carry out on economic evaluation. Firstly, permission is needed to conduct such research which related to the economics of the GMRP. This permission could not be obtained. Secondly, there are rapid changes in the Libyan market following the lifting of United Nation sanctions. These changes are in some instances on a monthly basis. Therefore, any economic evaluation can quickly become outdated.

The FAO framework is based upon a philosophy which involves matching the requirements of each land utilisation type with the available land resources. In this process, land resources are described as land qualities and land characteristics (Figure 4.1). The procedures to be followed depend upon the objectives, the level of the detail of the study, and the degree of integration of the economic information (Van Diepen et al., 1991). The procedures of the FAO Framework comprise the following activities:

- Selection of relevant kinds of land use and the requirements of these land use types;
- Description of land units and assessment of land qualities;
- Land use requirements are matched with land qualities for each land use;
- Suitability classification.

Land qualities represent the result of the interaction between a series of land properties which have a direct influence on land suitability for specific uses, for example, water availability and rooting conditions (FAO, 1976; FAO, 1983). In the next sections, land utilisation types and land use requirements are identified and examined within the study area.

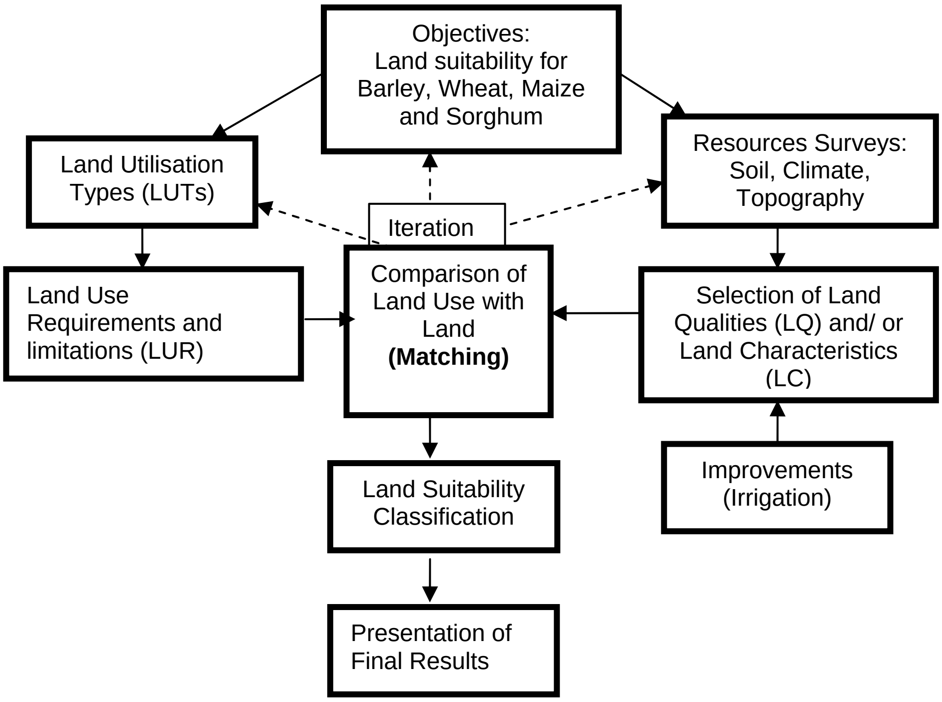


Figure 4. 9 Outline of the land suitability evaluation process
Source: FAO (1976)

4-3 Land Utilisation Types (LUTs)

4-3-1 Land Utilisation Types Overview

The land utilisation types (LUTs) represent land uses in more detail than general land use categories according to a set of technical specifications in given physical, economic and social settings. The selection of land utilisation types is one of the basic requirements of applying the FAO Framework for land evaluation (FAO, 1976; 1983).

The value of the results will be determined by the relevance of this selection as measured against the expectations.

There is no structured methodology to select LUTs for a given area. The FAO guidelines identify different factors that determine alternative land uses, namely: existing land use, prevailing rainfall and other climatic elements, physical and chemical characteristics of soil, and social and economic conditions necessary for their success (Rondal, 1984; Van De Putte 1989).

Beek (1978) states that there are three reasons behind the need to define land utilisation types. Firstly, accurate information is needed about land use performance and thus land evaluation findings are increasingly included within development plans. Secondly, land utilisation types provide a range of alternative technical possibilities to solve the problem of bringing together environmental, social and technical criteria and limitations in land use planning. Thirdly, land utilisation types provide land use planners with information based on unified concepts and procedures for any kind of use so that comparisons and cross referencing are facilitated.

Defining land utilisation types allows the identification of specific requirements of each land utilisation type and accordingly, how land that is being evaluated will meet these requirements (FAO, 1976; 1983; Beek; 1978).

4-3-2 Land Utilisation Types specification

There are a variety of factors that may be included within the characterisation of land utilisation types according to the purpose of the land evaluation study. Physical, economic and social settings form a background to all the land utilisation types of an area.

The land utilisation type consists of technical specifications within a socio-economic setting. As minimum requirement the nature of production must be specified. A single crop can be regarded as a land utilisation type only provided a statement is made as to the socio-economic setting in which it is cultivated, as productivity will vary considerably according to the technology available to the farmer (FAO, 1983). At more detailed levels of evaluation it is normally appropriate to regard the farming system or cropping system as the definition of land utilisation types.

FAO (1983) recognises three levels of land utilisation type description: summary, intermediate and detailed. The degree of detail with which land utilisation types are described varies according to the intensity and purposes of the evaluation. In low-intensity studies and those in which the land utilisation types are fixed at an early stage, intermediate length descriptions are usually appropriate (Beek, 1978).

In reconnaissance studies, the descriptions correspond to major divisions of rural land use, e.g. rain-fed or irrigated agriculture, grassland or forestry. However, for detailed studies, more information on the management conditions is required since, in practice, these strongly influence the attainable levels of production. In these studies, a land use option is described using the following set of management-related attributes and socio-economic settings that together define a land utilization type (LUT): level of inputs, produce, market orientation, capital intensity, labour intensity, mechanisation, infrastructure, infrastructure, land tenure (FAO, 1983; 1985). Brief descriptions of these attribute are given in the following sections.

- **Level of inputs**

It refers to material inputs such as seeds, fertilizers, pesticides. Three levels of inputs can be recognised: low, intermediate inputs and high inputs. Low inputs can be defined as no significant use of artificial fertilizers or improved seeds, pesticides or machinery.

Intermediate input is the practise of following agriculture services who have limited knowledge and capital resources. These inputs are adequate to increase yields but not to achieve maximum yields. High input is the method based on advance technology and high capital resources: fertilizers at levels of maximum economic returns and modern methods are employed to maximum yields (FAO, 1983; 1985).

- **Produce**

It refers to the crop grown and a statement should be made about the crop or corps to be grown, e.g. maize (FAO, 1983). Crop variety should be specified, if it has a significant effect on the productivity or management of LUT.

- **Market Orientation**

It is the degree to which the farming is directed towards subsistence or commercial production. This can be qualitatively described. FAO (1983) suggested the following four descriptions of market orientation: subsistence, subsistence with subsidiary commercial, commercial with subsidiary subsistence and commercial. However, subsistence may include cash sale of limited quantities of total production, on the other hand, commercial farming may include limited consumption of own produce. This can be expressed as a percentage of total production.

- **Capital Intensity**

It refers to the level of investment and recurrent costs on the farm. This attribute can be qualitatively described (FAO, 1983). Three levels of capital intensity can be described: high capital intensity, medium capital intensity and low capital intensity. High capital intensity land utilisation types include vegetables and high yielding varieties field crops. Medium capital intensity land utilisation types include cultivation of annual crops by commercial orientated small farms. Low capital intensity levels are normal traditional small farms.

- **Labour Intensity**

Labour intensity can be defined as the amount of human labour committed to the farm, per unit area of land. Both family labour and hired labour are included (FAO, 1938; 1985). Labour intensity can be qualitatively divided into there classes: High, medium and low. In high labour intensity, the labour input such as labour in non-mechanised farms. FAO (1983) state that labour intensity can be considered as high when more than 2.5 man-months per hectare. Medium labour intensity is the level defined between high and low. Low labour intensity is the level where labour less than 0.25 man-months per hectare (FAO, 1983).

- **Mechanisation**

This attribute refers to the extent of mechanisation on the farm. Qualitative description can be used. Three classes can be recognised: mechanised farming, partly mechanised farming and non mechanised farming (FAO, 1983; 1985). In mechanised farming, farming operations are conducted largely by power driven machinery.

- **Infrastructure Requirements**

Infrastructures play a vital part in the development plans. Land utilisation types need a ready access to market, factories, distribution centre of improved seeds and other advisory services (FAO, 1983).

- **Land Tenure**

This attribute describe the ownership or the right to use of land. There is a wide range of circumstances. FAO (1983) classified land tenure broadly to four categories: private ownership, tenancy, communal ownership and state ownership.

4-3-3 Land Utilisation Types for the study area

As noted the irrigation scheme is proposed in the case study area to accommodate four main crops (barley, wheat, maize and sorghum) to meet local requirements for these strategic commodities. The irrigation scheme aims to:

- provide a good opportunity for the coastal aquifers to recover part of the groundwater lost over the previous years;
- cultivation and development of large areas of land which remain currently idle through lack of sufficient irrigation water;
- agricultural expansion to encourage people in rural areas to remain on their land, thus relieving the population pressure in big cities such as Benghazi (GMRP, 1990).

The agricultural development is planned for large farms between 1,600 and 2,000 ha each run under the supervision of the Agricultural Service Centre in each area. These farms aim to produce cereal and to be equipped with modern machinery and overhead sprinklers for irrigation (Plate 4-1). The irrigations system can be divided into two levels of distribution. The primary network takes water from the main pipeline system at the end of the reservoirs (reservoirs located in Benghazi and Ajdabiya) to the agricultural reservoirs (will constructed in the potential farms), relying on gravity flow where possible but with some pumping stations for the higher level reservoirs. From the agricultural reservoir, water is to be pumped to the farms at the pressures required for the irrigation equipment (GMRP, 1990). Descriptions of LUTs in the study area are given in Table 4.4, 4.5, 4.6 and 4.7.

The centre-pivot system was selected by GMRP to irrigate all state farms in the north east of Libya. The centre-pivot system used in large farm installations offers efficiency in energy and water usage. It also requires the least amount of labour of any of the sprinkler systems. These two advantages are the principal reason the pivot-system tends to be adopted. It was known and recognised that differing irrigation practises may affect certain properties of soil. In many irrigated areas around the world, rising water tables have subsequently led to waterlogging and associated salinity problems. This has often happened where drainage development has not kept pace with irrigation development or where maintenance of drainage facilities was largely neglected. In this research, the impact of irrigation systems on soil properties were taken into account in the choice of the selected threshold values of soil salinity, soil drainage and slope. The selections proposed and further explanations are outlined in chapter five.

Plate 4.1 Typical irrigation of wheat field using overhead sprinklers

Table 4. 4 Definition and description of LUT1 in the study area

Attribute	Description
Level of Inputs	High (High yielding cultivars including. Optimum fertilizer application. Chemical pest, disease and weed control. Full conservation measures)
Produce & production	Irrigated Barley
Market Orientation	Commercial
Capital intensity	High
Labour intensity	Low
Mechanisation	Motor-driven machinery
Infrastructure	Market accessibility essential. High level of advisory services and application of research findings.
Land Tenure	State farms owned and operated by government
Water inputs	Carefully controlled irrigation pumped from the agricultural reservoir in the area

Source: (developed by the author)

Table 4. 5 Definition and description of LUT2 in the study area

Attribute	Description
Level of Inputs	High (High yielding cultivars. Optimum fertilizer application. Chemical pest, disease and weed control. Full conservation measures)
Produce & production	Irrigated Wheat
Market Orientation	Commercial
Capital intensity	High
Labour intensity	Low
Mechanisation	Motor-driven machinery
Infrastructure	Market accessibility essential. High level of advisory services and application of research findings.
Land Tenure	State farms owned and operated by government
Water inputs	Carefully controlled irrigation pumped from the agricultural reservoir in the area

Source: (developed by the author)

Table 4. 6 Definition and description of LUT3 in the study area

Attribute	Description
Level of Inputs	High (High yielding cultivars including. Optimum fertilizer application. Chemical pest, disease and weed control. Full conservation measures)
Produce & production	Irrigated Maize
Market Orientation	Commercial
Capital intensity	High
Labour intensity	Low
Mechanisation	Motor-driven machinery
Infrastructure	Market accessibility essential. High level of advisory services and application of research findings.
Land Tenure	State farms owned and operated by government
Water inputs	Carefully controlled irrigation pumped from the agricultural reservoir in the area

Source: (developed by the author)

Table 4. 7 Definition and description of LUT4 in the study area

Attribute	Description
Level of Inputs	High (High yielding cultivars including. Optimum fertilizer application. Chemical pest, disease and weed control. Full conservation measures)
Produce & production	Irrigated Sorghum
Market Orientation	Commercial
Capital intensity	High
Labour intensity	Low
Mechanisation	Motor-driven machinery
Infrastructure	Market accessibility essential. High level of advisory services and application of research findings.
Land Tenure	State farms owned and operated by government
Water inputs	Carefully controlled irrigation pumped from the agricultural reservoir in the area

Source: (developed by the author)

4-4 Defining Land Use Requirements

For each land utilisation type it is necessary to establish: the best conditions for its operations, the acceptable range of conditions which are less than optimal and the conditions that are unsatisfactory (FAO, 1976; 1983).

The term '*requirement*' is commonly used when describing the specific land conditions required for the proper functioning of a certain crop (or agricultural implement). For example, requirements include: water, nutrient and seedbed conditions for certain crops. These land requirements are the most fundamental aspects of the land utilisation type for the purpose of land evaluation (Beek, 1978).The availability of information about these land requirements is a critical aspect of land evaluation, especially in developing countries. This information is often very difficult to obtain, and may be incomplete or unspecific. Advanced information on the relevant land utilisation types and their land requirements will increase the effectiveness and reduce the cost of the field surveys and the studies on which land evaluation is based (Dent and Young, 1980).

Vink (1975) stated that there is no easy solution to the problem of collecting land use requirements data. Local and regional experience and the circumstances, under which these were found, will have to be carefully studied and compared in order to systemise knowledge and experience in this field. Therefore, in this research local and worldwide experience is brought together to identify the best prediction of the land use requirements.

It is not common to find handbooks on the cultivation of crops giving the ideal local land conditions. Such knowledge must be gathered from a literature review of optimum crop requirements and is used in building the land use requirements. This information and knowledge may then be used for the delineation of critical limits of land characteristics and qualities and establishment of crop production/suitability requirements. These critical limits are matched with data from the study area (Land Mapping Units) to determine the land suitability. The next sections explain the requirements of the selected crops based on the literature and local experience where it is available.

4-4-1 Barley

Barley is the world's fourth most important cereal crop, after wheat, maize and rice (Rasmusson, 1984). Much of the world's barley-producing regions have climates unfavourable for the production of other major cereals. Barley grows as a crop in marginal winter rainfall areas in which its life cycle is completed rapidly. Barley is grown in a wide range of photoperiods. In areas such as California (U.S.A) and North Africa, spring-type barley is grown during short winter days, whereas in the northern latitudes of Canada and Europe, it is grown during long summer days (Cuitard, 1960).

Barley is grown in Libya on the coastal strip where there is enough rainfall to meet the water requirements. Barley production and area harvested are directly related with the quantity of rainfall for a certain year. Figures 4-2 and Figure 4-3 show the harvested area and production of barley respectively.

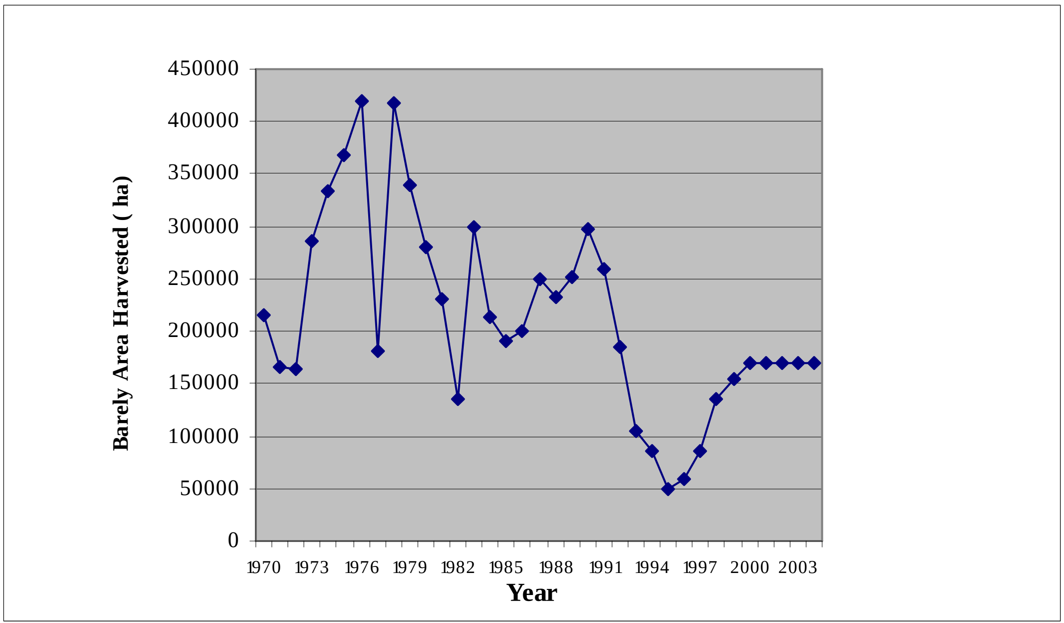


Figure 4. 2 Barley Area Harvested (ha) in Libya from 1970 to 2004
Source: FAOSTAT (2004)

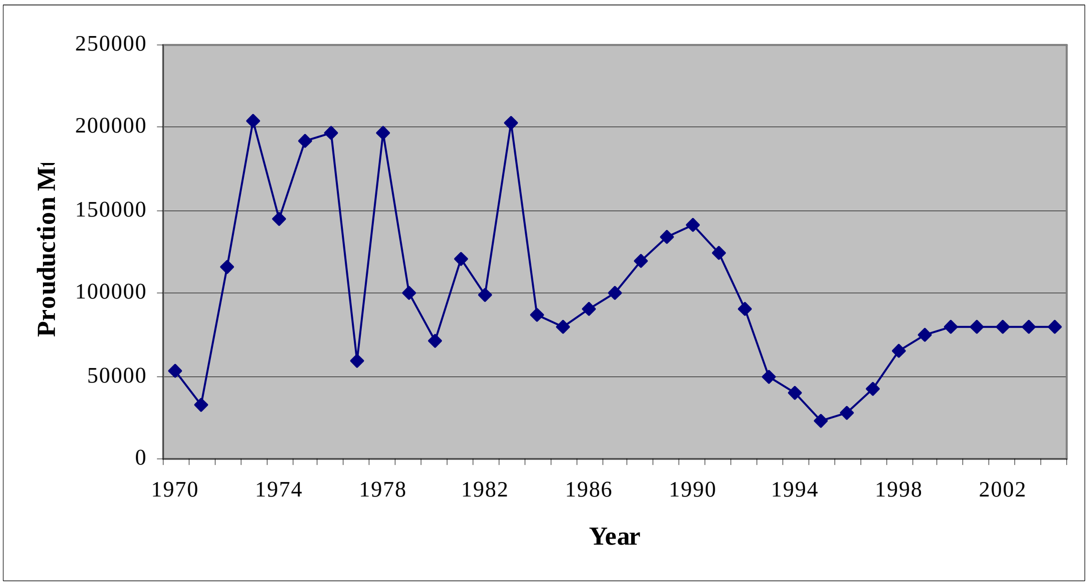


Figure 4. 10 Barley production in Libya from 1970 to 2004
Source: FAOSTAT (2004)

4-4-2 Wheat

Wheat is one of the most important cereals in terms of total world arable production. Despite the fact that wheat is considered a temperate-zone crop, it is also grown during the cool season in semi-arid areas in the subtropics and tropics. The origin of wheat is found in Mediterranean countries and today the major producing countries are U.S.A, China, India, France and Turkey (ILACO, 1989).Wheat needs at least 240 mm of well-distributed rainfall, although the crop is relatively drought tolerant. The growing period is between 120-210 days, depending on variety, temperature and day length. Soils best suited to wheat are medium to relatively heavy soils with good internal drainage. The crop is fairly resistant to salinity, as an EC_e of 7 mmhos/cm results in a yield reduction of about only 10 %. In semiarid regions with irrigation, wheat is grown in the winter period, preceding rice or cotton. Without irrigation only one crop of wheat can be grown annually (Arnon, 1972a). In Libya, wheat is grown in the coastal strip where the rainfall rates meet the water requirements. Figure 4.4 and Figure 4.5 shows the Area harvested and production of the wheat from 1970 to 2004.

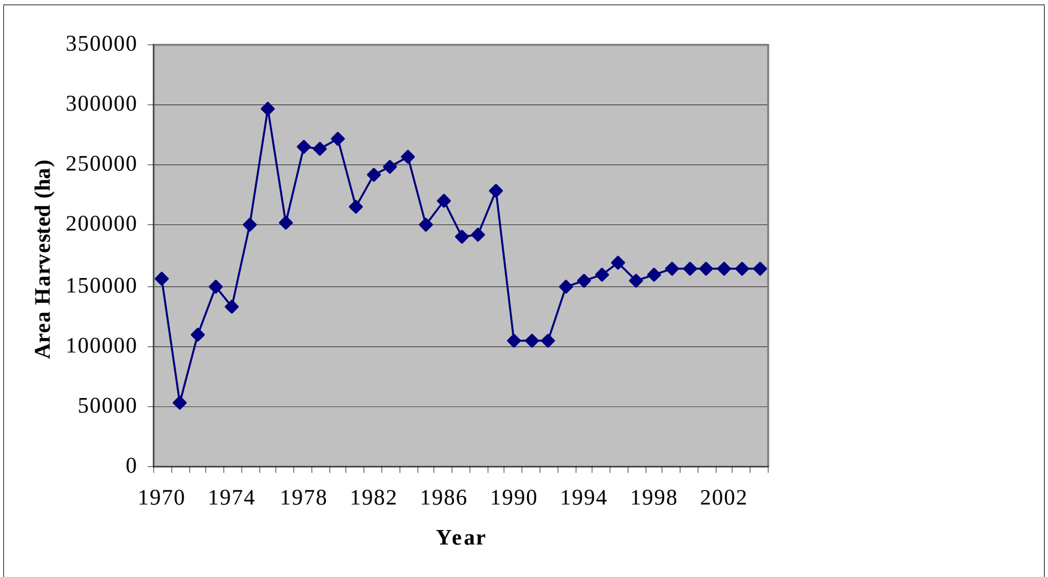


Figure 4. 11 Wheat Area Harvest (ha) in Libya from 1970 to 2004
Source: FAOSTAT (2004)

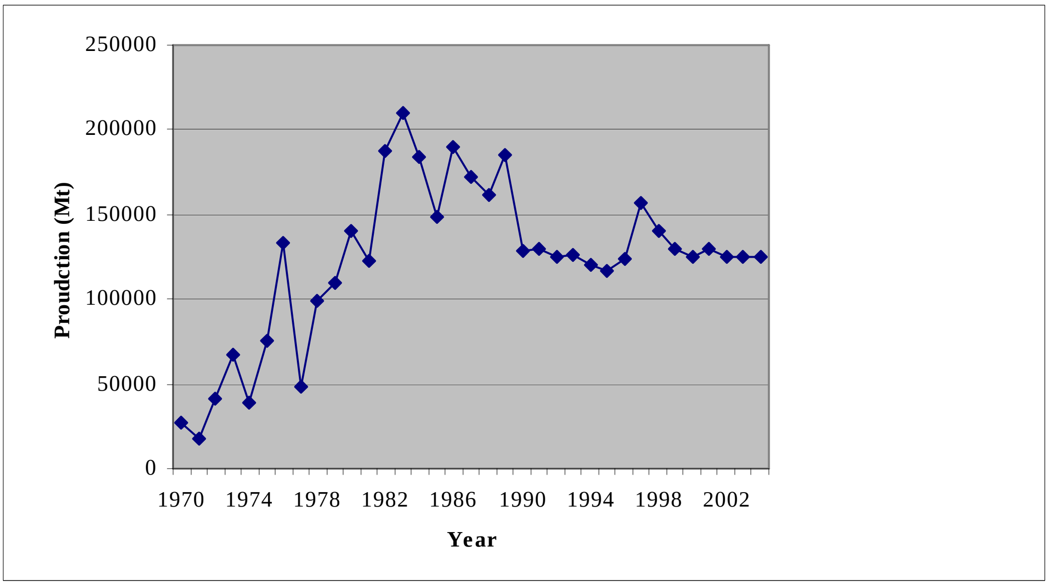


Figure 4. 12 Wheat production (Mt) in Libya from 1970 to 2004
Source: FAOSTAT (2004)

4-4-3 Maize

Maize is the most important cereal in the world after wheat and rice. The crop can be grown in Canada, United States, Mexico and Central America. Maize is grown in Africa, Central Europe and Asia (Stocskopf, 1984).

Such a wide range means the crop is universal in adaptation. Maize is used for three main purposes: (1) as staple human food, (2) as feed for livestock, and (3) as raw material for industrial products.

Maize is grown in Libya in the south area where the irrigation provides the necessary water requirements for the crop. Figure 4.6 and Fig 4.7 shows the maize area harvested and production in Libya from 1970 to 2004.

Generally, maize has a growing season of 90 days for early- maturing varieties and up to 140 days for late-maturing varieties (ILACO, 1989; Stocskopf, 1984).

Maize requires a warm, sunny climate where the moisture supply is adequate during the growing season although it is cultivated in more divergent climates than other cereal (Martin, 1984). Maize requires a frost free growing period. It is very sensitive to frost and very high temperature during the germination and tasselling stages (Bland, 1970; Pearson, 1984; Purseglove, 1984). Larson and Hanway (1977) indicate that temperature, water, nutrients, and physical conditions of the seedbed are the environmental factors of critical importance to maize growth between planting time and emergence. The optimum temperature for germination is 18-21° C; below 13 ° C this is greatly reduced and it completely fails below 10 ° C. Similar claims are also made by Pearson (1984), Martin (1984), ILACO (1989) and, Schneider and Gupta (1985).

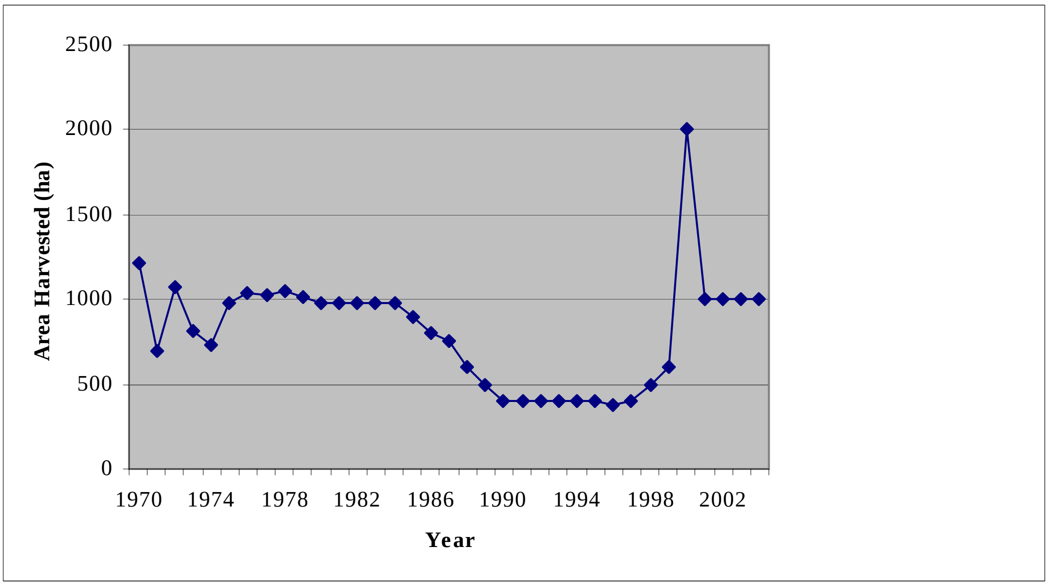


Figure 4. 13 Maize Area Harvested (ha) in Libya from 1970 to 2004
Source:FAOSTAT (2004)

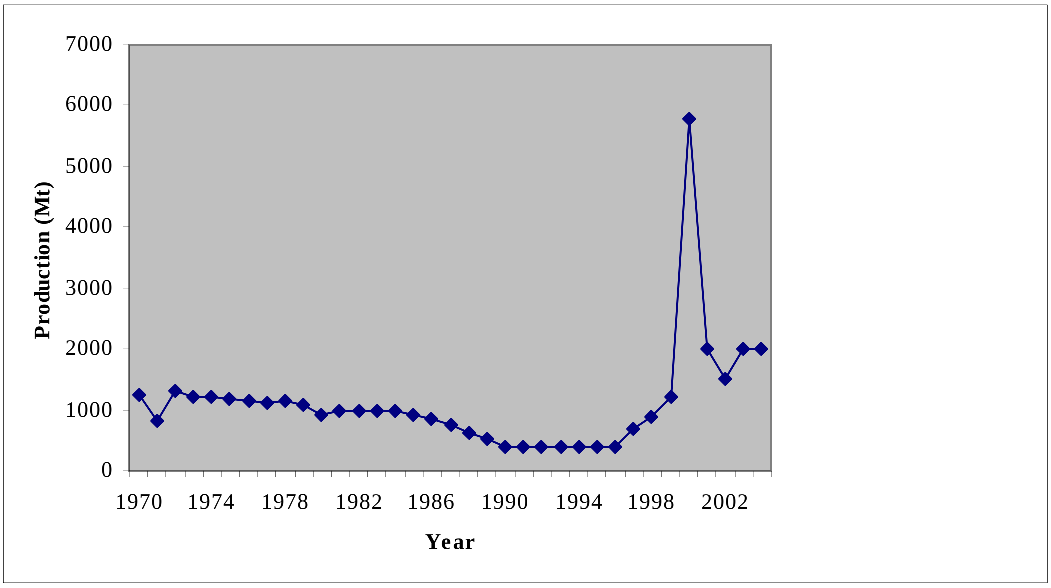


Figure 4. 14 Maize production (Mt) in Libya from 1970 to 2004
Source: FAOSTAT (2004)

High temperatures also affect nutrient uptake by maize. Mackay and Barber (1984) found that P uptake increased 4 times when the temperature increased from 18° C to 24° C. Not only the P uptake was seen to increase but also the root growth increased nearly four fold when the temperature rose from 18 ° C to 24 °C.

Water requirements are moderately high at 400-600 mm during the growing season. The distribution of precipitation is very important because maize is not a drought-resistant crop (Maize Production Manual, 1982; ILCAO, 1989; Landon, 1983).

Nearly all physical, chemical and biological conditions of soil affect maize growth. Unfortunately, the literature concerning the direct effect of soil properties is limited. In general, ideal soils for maize production are defined as deep, well drained, medium textured, high in nutrients and salt free (ILCAO, 1989; Landon, 1983; Bland, 1970; Pearson, 1984; Purseglove, 1984). At high pH levels, nutritional problems with the elements P, Zn, Fe often occurs in the pH range 7.4 - 8.0 (Clark, 1982).

Maize is not a salt-tolerant crop; a slight increase in salt levels reduces the yield significantly. Conductivity in the range of 1-4 dS/cm will usually cause no damage to maize (ILCAO, 1989). According to (Bernstein, 1964) the EC value for optimum maize growth is 4 dS/cm.

4-4-4 Sorghum

Sorghum is a drought-resistant crop and therefore well suited to arid areas. Its branched root system is very efficient in extracting moisture from the surrounding substratum (ILCAO, 1989). The origin of sorghum is Africa and the major producing countries are U.S.A, India, Nigeria, Argentina and Sudan.

The minimum annual rainfall requirement of a rainfed crop is 240 mm. Good yields are only obtained with a precipitation of 600 mm or over, however sorghum is drought resistant and also to a certain degree can also withstand water logging. The optimum average daily temperature is 30° C and sorghum cannot withstand frost.

Sorghum can tolerate a wide range of soil conditions. It grows well in heavy soils, but is also tolerant of light sandy soils. It yields relatively well in poor soils because of its efficient root system. Sorghum can be produced across wide range of pH from 4.0 to 8.4 (ILCAO, 1989; Landon, 1984)

Sorghum is moderately resistance to salinity since an EC_e of 6 mmhos/cm gives a yield reduction of only 10 %. It tolerates salinity better than maize; EC_e initial yield decline threshold, 4 mS cm^{-1}, 40% yield reduction at 11 mS cm^{-1} (Bouchet, 1983; Doggett, 1970; Wall & Ross, 1970; ILCAO, 1989; Landon, 1984). Tables 4.3 and 4.4 summarise the requirements of the selected crops.

Table 4. 8 Soil requirements and tolerances for the selected crops

Crops	Requirements for					Tolerance of				
	Water	Clayey texture	Good structure	Calcium	Acid	Water logging	Drought	Clayey texture	Acid condition	Salinity
Barley	L/M	L	L	L	L	L	M/H	M	M	H
Wheat	L/M	H	H	H	L	L	M	M/H	L	M
Maize	L/M	L	M	L	L	L	M/H	L	L	L/M
Sorghum	L/M	L	L	L	L	M	H	H	L	M

L=low, M= medium, H=high,

Sources: (McRae and Burnham, 1981; Vink 1974)

Table 4. 9 Indicative climatic and soil requirements for selected crops

Crop	Total growing Period (days)	Mean daily temperature for growth (°C) optimum and range	Day length requirements for flowering	Specific climatic constraints /requirements	Soil requirements	Sensitivity to Salinity
Barley	90-120	(14-20) (10-40)	Day neutral/short day	Resistant to frost during dormancy, drought resistant, tolerates salinity, lower temperature causes less damage than higher ones	Loam of light clay soil is preferred, a pH range of 6-8.4	Low sensitivty
Wheat	180-240	(14-20) (10-24)	Day neutral/long day	Resistant to frost during dormancy (>14 ° C), sensitive during post-dormancy period; requires a cold period for flowering during early growth. Dry period required for ripening	Medium texture is preferred; relatively tolerant to high water- table: pH 6-7	Moderately sensitive
Maize	100-140+	(24-30) (14-34)	Day neutral/ short day	Sensitive to frost: for germination, >10 °C; cool temperature causes problem for ripening	Well-drained and aerated soils with deep water-table and with out water logging : optimum pH 4-7	Moderately sensitive
Sorghum	100-140+	(24-30) (14-34)	Short day/day neutral	Sensitive to frost: for germination, >10 °C; cool temperature causes head sterility	Light to medium/heavy soils relatively tolerant to periodic water logging: pH 6-8	Moderately sensitive

Sources: (Vink, 1974; Landon, 1984; EUROCONSULT, 1988)

4-5 Defining Land Qualities and Land Characteristics

The requirements of given land utilisation types are compared with the properties of mapped areas of land by means of land qualities and characteristics. Land qualities are dynamic attributes and are assessed from land characteristics that are land attributes that can be measured or estimated (Dent and Young, 1980; Davidson, 1992).

The term 'quality' was used by Kellogg in 1943 to distinguish between two groups of properties that are important for evaluating the behaviour and potentialities of soils (Beek, 1978). Firstly, the characteristics that can be observed directly in the field and examined from representative soil samples in the laboratory, and secondly the qualities that may be interpreted from the observable characteristics and the results of field trial (Beek, 1978)

The concept of land quality was adopted in Brazil under the name of limitation and in methods of land evaluation published by FAO (1976). Bennema (1976) used the term 'major land qualities' and defined them as: "*a complex attribute of land which acts largely as a separate factor on the performance of a certain use. The expression of each land quality is determined by a set of interacting single or compound land characteristics with different weights in different environments depending on the values of all characteristics in the set*" (Beek, 1978).

The distinction between land characteristics and land qualities may be illustrated by comparing slope angle, a land characteristic, with erosion hazard, a land quality. Slope angle is a single and measurable property and therefore a land characteristic.

It can affect land use in several different ways: higher slope angles increase the erosion hazard, decrease the potential for mechanisation and reduce access within the production unit. Erosion hazard is a property which has identifiable and distinctive effects upon land use and is thus a land quality. It is influenced not only by slope angle but also by slope length, rainfall intensity and soil texture. The quantity of the erosion hazard results from the interaction of these characteristics.

There are other cases in which a land quality can be measured or estimated by a single land characteristic (FAO, 1983; Dent and Young, 1980; Davidson, 1992). For example, the quality of drainage affects land use in a distinct way, in that with the exception of rice and a few other specialised crops, most plants require oxygen in the rooting zone. A mild degree of drainage impedance reduces growth and crop yield. Severe impedance results in the death of the plant.

The most direct way to measure drainage conditions would be to monitor redox potential within the rooting zone throughout the growing period. But this is impracticable except under experimental conditions. For practical land evaluation, an easily measured land characteristic has to be used such as depth to the water table at some period of the year and soil drainage classes (Davidson, 1992).

4-6 Selection of Land Qualities and / or Land Characteristics

Land suitability classification is based upon the matching between land utilisation types and land use requirements for the land mapping unit. For the matching purposes, the FAO Framework recommends the description of land in terms of land qualities.

The FAO Framework suggests that it is possible to use the following means as a basis of land suitability assessment:

- Land qualities measured or estimated by means of land characteristics ;
- Land characteristics;
- A mixture of land qualities and land characteristics.

It is very important to distinguish between land qualities and land characteristics. Land characteristics represent an attribute of land that can be measured or estimated. Examples include slope angle, rainfall, soil texture and available water capacity. Conversely, a Land quality represents a complex attribute of land acting in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities may be expressed in a positive or negative way. Examples include moisture availability, erosion resistance and flooding hazard.

Land characteristics are simpler to use, and in a local context, they can provide a valid basis for estimating suitability classes. The main problem is that no account is taken of the interaction between different characteristics. One consequence of the failure to take into account the interaction is that the evaluation is applicable only to the area for which they were drawn up. Whereas the advantage of using land qualities is that they have distinct influences on specific kinds of land use. This is independent from the other qualities; therefore, there is no interaction between qualities, which allows each quality to be related to an economic value in the case of economic evaluation. Moreover, the total number of land qualities is less than the number of land characteristics (FAO, 1976; Van Diepen et al. 1991; Rossiter, 1996).

The advantage of using land characteristics is that the evaluation procedure is simpler and direct, permitting a direct comparison between the characteristics observed and the suitability rating. The disadvantages are the very large number of resulting characteristics. This large number of characteristics does not emphasise the effect of a single land characteristic (favourable or unfavourable) upon the crop suitability.

The choice between land qualities and /or land characteristics is a very important aspect of the land suitability assessment process. There is no single rule to guide this decision, which can be affected both by the circumstances of the survey and by personal preferences. The FAO recommends that the assessment should be based upon land qualities, although it is recognised that there are circumstances in which the use of land characteristics may be more convenient (FAO, 1976; 1983).

It suggests that as a general rule it is better to start by assessing land use requirements in terms of land qualities. This directs attention to the ways in which the various uses can be favourably or adversely affected. It is in any case necessary that decisions be taken based upon which land characteristics are to be used to measure or estimate the land qualities (Dent and Young, 1980).

The first step is the description of the land utilisation types with the second step being the determination of land quality and characteristics of land that are used in the suitability assessment. For each land utilisation type, there are four steps, thus: selection of relevant land qualities to the land use within the survey area; selection of land characteristics to be used to measure each of the selected land qualities; determination of the threshold values which will form the boundaries of suitability classes; and determination of how ratings based on individual qualities are to be combined into overall suitability (Dent and Young, 1980; Davidson, 1992; FAO, 1983).

The FAO lists 25 land qualities that affect suitability for crops and with many hundreds of land characteristics (FAO, 1976; 1983). Three groups of land use requirements can be identified: physiological requirements, management requirements and conservation requirement. FAO suggested a list of land qualities which should be considered for land suitability assessment (Table 4.4). Some of these land qualities are only applicable for certain crops or certain areas, so the land qualities that need to be considered in one evaluation will often be 14 or less. The way in which land affects the suitability for use is directly related to the land qualities, for example, nutrient supply and erosion hazard.

The selection of land qualities is based on three criteria:

- the quality has an effect upon the land use;
- critical values are available in the study area;
- there is some practicable means of collecting information about the quality (Dent and Young, 1980; FAO, 1983).

Table 4. 10 List of land qualities for assessing land suitability classification

Land Qualities
(A) Crop Requirements
1-Radiation Regime
2-Temperature Regime
3-Moisture Availability
4-Oxygen (soil drainage)
5-Nutrient availability
6-Nutrient Retention
7-Rooting conditions
8-Conditions affecting germination
9-Air humidity as affecting growth
10-Conditions for ripening
11-Climatic hazards
12-Excess of salts
13-Soil toxicity
14-Pest and diseases
(B) Management Requirements
15-Soil workability
16-Potential for mechanisation
17-Conditions for land preparation and clearance
18-Conditions affecting storage and clearance
19-Conditions affecting timing of production
20-Access within the production unit
21-Size of potential management units
22-Location: existing/ potential accessibility
(C) Conservation Requirements
23-Erosion hazard
24-Soil degradation hazard
25-Flood hazard

Source: FAO (1976; 1983; 1985)

Land quality of importance in one environment may not be important in other environments. This is demonstrated through wide range of land evaluation research throughout the world. In Brazil, the Soil Survey and Conservation Service of the Ministry of Agriculture has developed its own system of land evaluation. The system permits each land utilization type to be classified into four suitability classes. Four land qualities are used to determine land suitability and they are: availability of water, availability of oxygen in the soil, resistance to erosion, and absence of impediments to the use of mechanised equipment. Each land quality has been defined at three to five levels of limitations (Beek, 1978).

Kalima and Veldkamp (1987) define two groups of land qualities in developing a land evaluation for Zambia: climatic land qualities (CLQ) and edaphic land qualities (EDQ). The first group are based on climatic characteristics of importance to agriculture while the second depend upon one or more soil characteristics. They rate these land qualities separately depending upon the requirements of the land utilisation types. This is achieved by determining yield reduction as a percentage of what the land utilisation type could produce under ideal conditions. As a result, the rating of land qualities can be done on a quantitative basis (Kalima & Veldkamp, 1987). Chinene (1991) reports the full development of the Zambian Land Evaluation System (ZLES) for rainfed agriculture, which evolved from the earlier study by Kalima and Veldkamp (1987).

Chinene and Shitumbanuma (1988) evaluate the suitability of a proposed state farm in Northern Zambia for commonly grown crops. In this study land qualities are assessed on the basis of soil survey data; Climatic data are excluded because a rainfed growing period of about 160 days usually occurs and this is adequate for most arable crops. For this study there was an absence of data on the performance of land use types in relation to the qualities; thus the author rated quality on a subjective basis, each quality from 1 (the best) to 4 (the worst) The qualities used were: soil moisture availability, oxygen supply to the root zone, and availability of plant nutrients and erodibility.

Ngowi and Stocking (1989) developed a land suitability assessment for coconuts in the Coastal Belt of Tanzania. A FAO Framework for land evaluation was conducted according to the guidelines for rainfed agriculture (FAO, 1983). Seven land qualities were considered in this evaluation, namely; moisture availability, erosion hazard, nutrient availability and retention, excess of salts, rooting conditions and tsetse. The land qualities were selected were the relevant ones to the local conditions (Ngowi and Stocking, 1989).

Yizengaw and Verheye (1994) assessed land suitability for barley, maize and teff following the guidelines of the FAO Framework (1976). The study concluded that the major factors affecting growth and production of crops are, climatic attributes, moisture regime, and specific soil and landscape attributes associated with conditions of rooting, wetness, fertility, excess of salts, ease of cultivation and risk of erosion. Therefore, only land qualities relevant to land use were considered, namely: moisture conditions, thermal conditions, rooting conditions, wetness conditions, fertility conditions, excess salt and ease of cultivations (Yizengaw and Verheyeb, 1995).

Wandahwa and van Ranst (1995) employed six land use requirements, namely; climate, soil fertility status, salinity hazard, alkalinity hazard, soil rooting conditions, and erosion hazard in land suitability assessment for pyrethrum. The FAO Framework was used to implement the land evaluation and only land qualities which affect the production of pyrethrum were considered (Wandahwa and Van Ranst, 1996).

Bydekerke *et al* (1997) adapted the FAO Framework (1976) to implement land suitability evaluation for Cherimoya in Ecuador. The objective was to identify the potential cultivation areas in this region. Climate, soil and landform were the criteria used as layers to drive overall land suitability (Bydekerke *et al*, 1998).

In Jordan, land qualities and their associated land characteristics were developed in the JAZPP (Jordan Arid Zone Productivity Project) which aimed to improve agriculture productivity in arid and semi-arid zones of Jordan. In this study a number of land utilisation types were evaluated with physical criteria set with respect to land qualities and characteristics to place the land into the appropriate classes for each land utilisation type (Hatten and Taimeh, 2001).

Messing *et al* (2003) developed a land suitability classification within the FAO Framework (1976) in China. Six land qualities and fifteen land characteristics were relevant as a basis of the classification. The selected land qualities were: available water, slope aspect, soil workability, erosion hazard, available nutrients and flooding hazard (Messing et al., 2003).

As recognised from the FAO Framework and previous land suitability classification, it is very importance to chose the most appropriate land qualities and / or land characteristics. The choices have their advantages and disadvantages. In this the research land qualities (LQ) measured or estimated by the means of land characteristics (LC) will be used as the basis for the assessment. This decision is taken firstly to allow for the interaction between land characteristics; and secondly to direct attention to the effect of land quality upon the land use. This makes conducting economic evaluation easier by using the land qualities.

4-7 Conclusion

The FAO Framework is based upon the comparison between land use requirements and land resources. The first step in applying the FAO Framework is to define land utilisation types. Defining land use requirements in terms of land qualities and/or land characteristics is the second step. Matching land use requirements with land resources is the final step. Selection of land qualities and/or land characteristics and their threshold values is a vital step. It is possible to use land qualities and/or land characteristics or a mixture of both. The selection depends upon the purpose of the evaluation and available data.

Land qualities (LQ) measured or estimated by the means of land characteristics (LC) are selected as the basis for the assessment in this research. The rationale for selecting land qualities is: to take into account the interaction between land characteristics and land qualities can be extremely useful in producing economic evaluations in future studies. In the next chapter, the selection of land qualities and land characteristics is introduced. In addition, the critical limits of land characteristics are examined and determined.

5

A Framework for Land Evaluation in Libya

This Chapter specifies the land qualities, land characteristics, and their threshold values for the study area.

5-1 Specification of Land Qualities and Characteristics in Libya

Land qualities (LQ) measured, or estimated, by the means of land characteristics (LC), have been selected as the basis of the land suitability assessment in the study area. This decision has been undertaken to take into account the interaction between land characteristics and because the land quality has direct effect upon the land use (Dent and Young, 1980; FAO, 1983).

The selection of land qualities and land characteristics has been accomplished by carefully considering the available texts and publication according to the following procedure:

- critical review for land resources and data available (Soil, Climate, Topography and Crop);
- critical review of literature, texts and publications;
- development of a provisional list of land qualities, land characteristics and their threshold values;
- meetings with local experts, visits to the study area and consultations with the authorities in Libya;
- development of final land qualities, land characteristics and their threshold values

The FAO suggest a number of land qualities for different land use through its publications (Table 4.4) (FAO, 1976; 1983; 1985). In this research, land qualities proposed by FAO were examined against three criteria: the effect of land quality upon use, the occurrence of critical value of land quality within the study area and the practicability of obtaining information on individual land qualities . A spreadsheet was formulated to examine the significance of each land quality. If the land quality was considered important or moderately important, the land quality was selected, while less important land quality was omitted from land suitability assessment (Table 5-1). The selection of land qualities were based upon three criteria. The first criterion is the effect of land quality upon use, which is given score from 1 to 3. Score 1 means that land quality has a large effect upon land use. Score 2 indicates that land quality has a moderate effect upon land use, while score 3 expresses that land quality has a slight effect upon land use. The second criterion is the occurrence of critical values within the study area. Three categories are recognised in this criterion: frequent, infrequent, and rare occurrence. A score 1 to 3 was given to the categories respectively. The third criterion is the practicability of obtaining information. These are classified as (a) available (Score 1), (b) not available, but obtainable by research (Score 2) and (c) not obtainable (Score 3).

Each land quality was examined against the three criteria to assess the significance of the quality. This significance was divided into three categories: very important, moderately important, or less important. Scores 1, 2, and 3 were given to the categories respectively. As a result, a score was obtained by selecting the numerically highest score of the three criteria and therefore the significance of the quality was identified. If the score of significance is 1 (important) or 2 (moderately important) the land quality employed while if the score was 3 (less important) the land quality was omitted.

Table 5. 1 Selection of land qualities through spreadsheet

Land Qualities	**Selection Criteria**			
(A) Crop Requirements	Importance for the use [1]	Existing critical values in the study area [2]	Availability of Data in the study area [3]	Significance [4]
1-Radiation Regime	2	2	3	3
2-Temperature Regime	1	1	2	2
3-Moisture Availability	1	1	1	1
4-Oxygen (soil drainage)	1	1	1	1
5-Nutrient availability	1	1	2	2
6-Nutrient Retention	1	1	1	1
7-Rooting conditions	1	1	1	1
8-Conditions affecting germination	1	1	1	1
9-Air humidity as affecting growth	2	3	3	3
10-Conditions for ripening	2	2	3	3
11-Climatic hazards	2	2	3	3
12-Excess of salts	1	1	1	1
13-Soil toxicity	1	1	1	1
14-Pest and diseases	1	1	3	3
(B) Management Requirements				
15-Soil workability	1	2	3	3
16-Potential for mechanisation	1	2	2	2
17-Conditions for land preparation and clearance	2	2	3	3
18-Conditions affecting storage and clearance	1	2	3	3
19-Conditions affecting timing of production	2	2	3	3
20-Access within the production unit	1	3	3	3
21-Size of potential management units	2	2	3	3
22-Location: existing/ potential accessibility	2	2	3	3
(C) Conservation Requirements				
23-Erosion hazard	1	1	1	1
24-Soil degradation hazard	1	2	3	3
25-Flood hazard	2	3	3	3

1= Importance of use with three scores: 1 **=** large effect upon land use; 2 = moderate effect upon land use; 3 = slight effect upon land use.
2 = Exiting of critical values with three scores**:** 1 = frequent, 2 = infrequent, 3 = rare occurrence.
3 = Availability of data with three scores**:** 1 = available, 2 = not available, 3 = not obtainable.
4 = Significance was derived by selecting the numerically highest score of the three criteria. Significance can be divided into three scores: 1 = important (selected), 2 = moderately (selected), 3 = less important (omitted).

The required land qualities and their associated land characteristics have been selected (Table 5.2).They have been aggregated into four main groupings. The criteria used have been those, which most directly affect crop growth of a particular land utilisation type. They are also those objectively measured and recorded in soil survey reports and climatic data. The definition and justification of these land qualities and land characteristics and their threshold values are explained in the following section.

Table 5. 2 Land qualities and Characteristics in the study area

Code	Grouping	Land Qualities	Land Characteristics	Unit
C	**Climate**	Temperature Regime	Mean Temperature in the growing season	C °
s	**Soil**	Rooting Conditions	Rootable Depth	cm
			Soil Texture	class
		Moisture Availability	Available Water-holding Capacity	mm m^{-1}
		Nutrient Availability	Soil Reaction	pH
		Nutrient Retention	Soil Organic Matter	%
			Cation Exchange Capacity (CEC)	me/100g s
		Excess of Salts	Soil Salinity (EC)	dS/cm
			Soil Alkalinity (ESP)	%
		Soil Toxicities	$CaCo_3$ in root zones	%
		Infiltration	Infiltration rate	mm hr^{-1}
		Condition for Germination	Gravel and Stones at surfaces	%
		Oxygen Availability	Soil drainage Class	Class
e	**Erosion**	Erosion Hazard	Soil Erosion (USLE model)	t ha^{-1} yr^{-1}
t	**Topography**	Potential for Mechanisation	Slope Steepness	%

Sources: (compiled by the author)

5-2 Climate Criteria (Temperature Regime)

Temperature affects plant growth in three main ways: growth ceases below a critical temperature (typically 5 °C); the rate of growth varies with temperature; and very high temperatures have adverse effects (FAO, 1975; 1979; 1983; 1985).

Crops can be divided into five adaptability groups on the basis of their photosynthetic carbon assimilation pathway and response of photosynthesis to radiation and temperature (Table 5.3). Between the minimum temperature of growth and the optimum temperature for photosynthesis, the rate of growth rises more or less linearly with temperature. The growth rate then reaches a plateau within the optimum temperature range before falling at higher temperatures.

Plants can grow only within certain limits of temperature. For each species and variety there are not only optimal temperature limits, but also optimal temperatures for different growth-stages and functions as well as lower and upper limits (Arnon, 1972a). In climates where the growing period is limited by low temperature such as in many temperate climates, the temperature for growth will be below the optimum during the early part of the growing season and rise as the season advances. In these circumstances, some measure of cumulative temperature over the growing season is appropriate (FAO, 1983).

FAO (1975, 1983) recommend two methods to measure the effect of temperature on crop growth. Firstly, the effects of temperature on growth, by taking mean monthly values for the growing season and calculating the mean temperature for this period; secondly, the adverse effects of high temperature, by using the mean monthly maximum temperature of the hottest month during the growing season, where this is believed to have adverse effects.

Table 5. 3 Crop adaptability Groups, based on photosynthetic pathway and response to radiation and temperature

Crop adaptability group	I	II	III	IV	V
Photosynthetic pathway	C_3	C_3	C_4	C_4	C
Optimum temperature for photosynthesis (ºC)	15-20	25-30	30-35	20-30	25-35
Crops	Sugarbeet, Phaseolus, Wheat, Barley, Oats, Potato, Bean (TE), Chickpea	Soybean, Phaseolus, Rice, Cassava, Sweet, Potato, Yams, Bean (TR), Groundnut, Cotton, Tobacco, Banana, Coconut, Rubber, Oil palm	Sorghum Maize Pearl millet Panicum Millet (TR) Finger millet, Setaria, Sugarcanes	Panicum Millet (TE, TH) Sorghum (TE, TH) Maize (TE, TH) Setaria, Millet (TE, TH)	Sisal, Pineapple

TE= Temperate cultivars, TR= Tropical (lowland) cultivars, TH= Tropical (highland) cultivars.

Source: FAO (1975)

Alsgear (1980) studied thirty-six different sites all over the North of Libya (18 in the North-West and 18 in the North-East). The study considered the distribution of the weather factors through the six months September to May, which is the agricultural season for the rainfed crops. From this study, it was recommended that the mean temperature during the growth season is the appropriate method to express the temperature effect on the crops (Jindeel, 1978; Selkhozpromexport, 1980) and support the conclusion of FAO (1975, 1983) and (Alsgear, 1980) .The threshold values of the land suitability classes for this quality are determined by gathering information from the literature review on the selected crops and soil survey on the study area.

In the following sections, critical limits to define the levels of suitability will be specified.

- **Barley**

Arnon (1972) states that barley can germinate at about 2 °C, but emergence is very slow at this low temperature; the optimum temperature for germination and emergence is between 14 °C to 20 °C. Although young barley plants have considerable tolerance to cold, the temperature at which vegetative growth proceeds normally is around 15 to 17 °C (Arnon, 1972). Nuttonson (1957) states that temperatures as high as 40 °C during ripening are reported to cause less damage to barley than to wheat. Since barley matures earlier than wheat, it may escape excessively high temperatures during grain formation. The threshold values are shown in Table 5.26.

- **Wheat**

Wheat varieties can be grouped into winter and spring types. The minimum daily temperature for measurable growth in both types is about 5 °C (Doorenbos and Kassam, 1986).

There are many claims about the optimal temperature in the literature. Arnon (1972) and Stoskopf (1985) state that the minimum temperatures for wheat are 3 °C to 4 °C; the optimum temperature is 25 °C and the maximum temperature 30 °C to 32 °C. Arnon (1972) made these claims referring to the adoption of wheat in regions. Purseglove (1985) made a slightly different claim when he indicated that the minimum temperature for growth is 4 °C and the optimum temperature for growth is 29 °C. Landon suggested from a range of literature that the optimum temperatures are 15 °C to 20 °C. FAO (1983) state the same figures, in relation to the climatic requirement of wheat in Mozambique. ILCAO (1989) indicated that a high temperature, as occurs in the Middle East (38-40 °C) may retard heading and cause the crop to ripen prematurely after flowering. The threshold values selected for the temperature are based on the literature reviews, especially those in dry regions (Table 5.27).

- **Maize**

Purseglove (1985) and Bland (1972) indicate that the optimum temperature for germination is 18-21 °C; below 13 °C, it is greatly reduced and fails below 10 °C. And also Pearson (1984), Martin (1984), ILCAO (1989), Schneider and Gupta (1985) made similar claims.

Berger (1952) states that 18.3 °C is the optimum germination temperature for maize. FAO (1983) indicate that 10 °C, 35 °C, 20-30 °C are the minimum, maximum and optimum temperature requirements for maize respectively. Arnon (1972) states that maize is a warm weather crop that is not grown where the mean summer temperature is less than 19 °C, and where the average night temperature during the summer months falls below 13 °C. He added that the growth of maize early in the season has been shown to increase linearly with soil temperatures from 15 °C to 27 °C and the critical temperature affecting yields, appears to be around 32 °C.

There are no studies about the temperature and its effect on maize growth in Libya, therefore the threshold values determined in this research are based upon the literature review only. The threshold values for the temperature suitability classes are shown in Table 5.28.

- **Sorghum**

Sorghum is a drought-resistant cereal and has the ability to produce good yields under conditions of low soil moisture and high temperature (Arnon, 1972).

Arnon (1972) claims that the minimum temperatures for germination are 7-10 °C, whereas the minimum temperature for growth is 15 °C with 27-30 °C for optimum growth. Purseglove (1985) and ILCAO (1989) also indicate that the optimum growth temperature for sorghum is 30 °C. Moreover, FAO (1984) state that the optimum temperature is 24 - 30 °C; minimum temperature is 15 °C and maximum temperature is 35 °C. Stoskopf (1985) state that sorghum germinates at a minimum temperature of 7 °C. The optimum temperature for germination is 15 °C and the flowering progresses normally at temperatures between 21 - 30 °C.

A similar claim is made by Landon (1984) when he states that the optimum temperature for growth is 24 -30 °C. Therefore, the threshold values for temperature are based on the literature review in order to define the limits between the suitability classes in the LUTs (Table 5.28).

5-3 Soil Criteria

Adequate agricultural utilisation of the climatic potentials and maintenance of land productivity largely depend on soil fertility and the management of soils on an ecologically sustained basis. Soil fertility is concerned with the ability of the soil to retain and supply nutrients and water in order to enable crops to maximise the climatic resources of a given location (FAO, 2002).

There are basic soil requirements for plants to grow, such as effective soil depth, available nutrients, soil fertility regime, soil aeration regime, absence of soil salinity and of specific toxic substances or ions deleterious to crop growth, and other properties which are required for germination and early growth.

In the following sections, these requirements are explained and the critical limits for them are identified.

5-3-1 Rooting Conditions

5-3-1-1 Soil Texture

Soil texture is the most important property to be determined and critical for understanding soil behaviour and management. From the soil texture many conclusions can be drawn. Soil texture governs the moisture and nutrient storage capacity. It provides a measure for permeability and to some extent for water retention capacity (Brady and Weil, 1999).

Soil texture is the most permanent characteristic of the soil. It decisively influences a number of soil attributes such as soil moisture regime, permeability, infiltration rate, run off rate, erodibility, workability, root penetration, and fertility (ILACO, 1989).Texture classes are defined by the relative contents of the three major soil separates, sand, silt, and clay. There are many systems to define soil texture such as international system, U.S.D.A system and Russian system.

Wheat and maize favour medium textured soils. Sorghum grows well in heavy soils. Alsgear and Kasam (1983) state that Libyan soils range from clay to sand soils. Although most of the soils in Libya are coarse textured (light), soils in the east of the country are heavy soils. Reports from ARC indicate that barley is the crop most suited to the Libya soils. Mahmoud (1995) reviewed these reports and trials from ARC and concluded that field crops can be divided into two groups. The first group (A) are crops that favour the heavy texture such as barley, wheat and maize. The second group are crops that favour the heavy texture with satisfactory production in the light texture such as sorghum. Table 5.4 shows the effect of soil texture on the crop yield in the Libyan soils.

Table 5. 4 The influence of soil texture on yield of selected crops

Soil Texture	Gravel and stones %	Decrease in the yield crops %	
		Group A	Group B
Sandy	1* 2 3 4 5	55 65 75 75 80	45 55 75 65 75
Sand Loam	1 2 3 4 5	45 55 70 65 75	35 45 65 55 70
Loamy Sand	1 2 3 4 5	35 45 65 55 70	25 35 60 45 65
Sand clay & Sandy Clay Loam	1 2 3 4 5	25 35 60 45 65	15 25 50 35 60
Loam	1 2 3 4 5	15 25 50 35 60	5 15 45 25 55
Silt & Silt Loam	1 2 3 4 5	5 15 45 25 55	0 10 40 20 55
Clay & Silt Clay	1 2 3 4 5	0 10 40 20 50	10 20 50 30 60
Silt Clay Loam	1 2 3 4 5	0 10 40 20 50	5 15 45 25 55

Source: (ARC, 1990; Mahmoud, 1995)

The threshold values of suitability classes for the selected crops were based on extensive review of the trials and reports from ARC and especially the reports from Benghazi and Al Marj area. These threshold values show in Table 5.5.

Table 5. 5 Limits for suitability classes of soil texture for the selected crops

Crop	S1	S2	S3	NS
Barley	Silt, Silty Clay Loam, Clay, Loam, Clay loam,	Sandy clay, Sandy Clay Loam	Loamy Sand	Sand
Wheat	Silt, Silty Clay Loam, Clay, Loam, Clay loam,	Sand clay, Sandy Clay Loam	Loamy Sand	Sand
Maize	Silt, Silty Clay Loam, Clay, Loam, Clay loam,	Sandy clay, Sandy Clay Loam	Loamy Sand	Sand
Sorghum	Silt, Silty Clay Loam, Clay, Loam	Sandy clay, Sandy Clay Loam	Loamy Sand	Sand

Source: compiled by the author

5-3-1-2 Rootable Depth

Rootable depth is a very important parameter in determining the quantity of water and nutrients that can be stored in the soil profile and the ability to support plant growth during periods of no rainfall or when irrigation ceases. Soil depth is also important in determining the ability of the profile to support plant rooting, and the ability of the crop to withstand wind damage. Under irrigated conditions soil depth affects drainage, aeration, and water retention properties. Deep soils favour drainage and are therefore optimal for irrigation of dry land crops.

Crops cannot be expected to yield satisfactorily beyond critical ranges of soil depth. Engelstad et al. (1961) found a positive correlation between soil depth and yield, which was also confirmed by Lindstrom et al. (1986). Stewart and Nielsen (1990) indicate that a soil depth of about 30-40 cm is the minimum depth for maximum yields of all crops. Significant decreases in production are evident for all crops where soil depth is less than 30 cm.

On the other hand, there is an optimum soil depth for crops. According to ILCAO (1989), the optimum soil depth for maize rooting is 50-90 cm. Landon (1983) indicates that maize roots can reach up to 200 cm but the main uptake is within 80-100 cm soil depth. Soil depth for high soil fertility should be greater than 100 cm and in conditions of low soil fertility should be greater than 150 cm (Maize Production Manual, 1982). Calvino et al. (2003) conducted a study aimed at investigating the influence of water availability and technological changes over 15 years on the yield of dry land maize crops in the Argentine Pampas. They found that shallow soils presented lower yield than deep soils at a given rainfall.

Mayaki et al., (1976) found that the root development under irrigation and rainfall conditions varied. The author indicates that in irrigated maize, 54% of the root dry matter was in the upper 30 cm with 92% between 0-90 cm. In non-irrigated maize, 30% of the total dry matter was in the upper 30 cm and 70% was in the range of 30-90cm depth. No maize roots were found below 150 cm.

Selkhozpromexport (1980) investigated the relationship between the soil depth and some cereal crops (barley, wheat, maize and sorghum) in north-east of Libya. The investigations showed that a soil depth of 50-80 cm is the most favourable for the growth and development of cereal crops (Figure 5.1). Selkhozpromexport observed that productivity of barley and wheat were around 40% in soil depth 0-30 cm, while the productivity increased to reach more than 90% in soil depth 50-80 cm.

GMRP (2002) made similar claims in trials set in the North West of Libya in the experimental farm of Fem Melga. The findings of the study confirmed that crops grown at a soil depth of less 30 cm gave the lowest production, whereas the yield markedly increased in soils with depths of more than 50 cm. Mahmoud (1995) states that crop production decreases with the decrease of soil depth especially in soil where there is a hard pan layer under the top soil (Table 5.6).

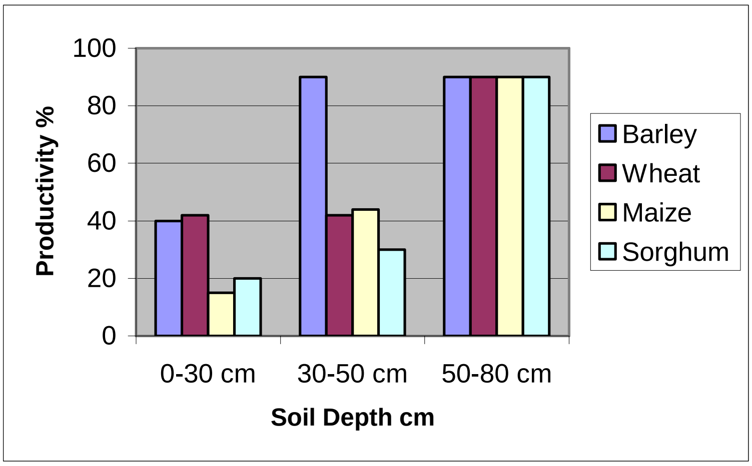


Figure 5. 1 Productivity response of field crops to varying soil depth

Source: Selkhozpromexport (1980)

Table 5. 6 Soil depth and crop production in Libyan Soils

Sub soil layer	Soil depth (cm)	The decrease in crop production (%)
No hard pan	> 150	0
	100-150	0
	50-100	20
	30-50	20
	< 30	50
Hard pan	>150	0
	100-150	0
	50-100	10
	30-50	30
	< 30	60

Source: Mahmoud (1995)

It has been suggested that a soil depth of less than 30 cm vastly decreases the crop yield In addition, it is agreed that a soil depth between 50 cm to 80 cm increases the crop yield (Selkhozpromexport, 1980; Stewart and Nielsen, 1990; Mahmoud, 1995; GMRP, 2002; FAO, 2002). Accordingly, the threshold values between land suitability classes for the four land utilisation types can be set.

The basis was the local studies and trials taking into account the studies in similar conditions. Table 5.7 show the suitability classes for the four crops and the critical limits between these classes.

Table 5. 7 Soil depth suitability ratings

Crop	Highly Suitable S1	Moderately Suitable S2	Marginally Suitable S3	Not Suitable NS
Barley	> 80	80-50	> 50-30	< 30
Wheat	>120	120-100	> 100-50	< 30
Maize	> 120	120-100	> 100-50	< 30
Sorghum	> 80	80-50	> 50-30	< 30

Source: (developed by the author)

5-3-2 Moisture Availability (Available Water-Holding Capacity)

Available water holding capacity (AWHC) is an important agronomic and hydrologic characteristic of soils. It expresses how much water can be stored in soils for plants to use during periods without rain or irrigation. This gives an indication of the drought sensitivity of soils, a key criterion in the selection of suitable crop species and varieties. Available water-holding capacity is defined as the volume of water retained between field capacity and the permanent wilting point (ILACO, 1989; Landon, 1984).

The available storage capacity of the soil and consequently the water application depth and irrigation frequency are determined by root depth and root distribution as well as by the moisture characteristics of the soil (ILACO, 1989). Landon (1984) states that AWHC of soil profiles can be used as a factor in land suitability classification and in irrigation planning provided the effective rooting depth, the percentage of root distribution and percentage of readily-available water is taken into account. He explained that whenever possible

AWHC values for suitability assessment should be derived from the particular crop varieties and cropping pattern on site. However, he introduced a general grouping for irrigation suitability (Table 5.8).

Table 5. 8 Groupings of AWHC values for irrigation planning

Rating for Irrigation Suitability	AWHC (mm m^{-1})
Low	< 120
Medium	120 – 180
High	> 180

Source: (Landon, 1984)

Calvino et al. (2003) state that there is a strong association between yield and available water during the period bracketing flowering in maize crops, adding that grain yield in the study area has steadily increased during a 15 years. Similar results were reported by Leeper et al. (1974) for the U.S corn belt. Hatten and Taimeh (2001) selected AWHC as a land characteristic in their land suitability assessment for different land utilisation types in Jordan. In the Jordan project, AWHC values of more than 150 mm m^{-1} were considered the upper threshold value and AWHC values less than 75 mm m^{-1} the lower limit. Selkhozpromexport (1980) made similar claims for cereal crops in the north-east of Libya. Yeha (1982) confirmed that these limits can be used in suitability classification for irrigation in Libya. Table 5.9 shows the threshold values of AWHC for the selected crops.

Table 5. 9 Suitability ratings for Available Water Holding Capacity (AWHC)

Suitability Classes	Available Water Holding Capacity (AWHC) (mm m^{-1})			
	Barley	Wheat	Maize	Sorghum
S1	> 150	> 150	> 150	> 150
S2	>110 – 150	> 110 – 150	> 110 – 150	> 110 – 150
S3	110 – 75	110 – 75	110 – 75	110 – 75
NS	< 75	< 75	< 75	< 75

5-3-3 Nutrient Availability (Soil Reaction)

Soil reaction (pH) affects a wide variety of chemical and biological phenomena in soils. The effect of soil pH is great on the solubility of minerals or nutrients. Brady and Weil (1999) state that soil pH is the master variable of soil, since it influences many physical, chemical, and biological properties and processes.

If the soil pH declines below a critical level, the solubility of aluminium and manganese ions increases, resulting in toxicity and lower yields. Soil acidity affects plant growth in several ways. Toxicity, caused by increased mobility of soil aluminium, is thought to be the most serious of these effects (Black, 1992). Aluminium becomes available when the pH drops below about 5.5. The cation exchange complex of soils becomes largely saturated with aluminium ions at pH 4.0. As a result, plants are deprived of essential cations (Foth and Ellis, 1997). Berglund (1996) states that a soil pH below 5 adversely affects roots and a pH below 4 severely restricts root growth.

If the pH is higher than 8.5 the soils are considered to be alkaline soils. This causes some essential nutrients such as magnesium (Mg) and calcium (Ca) to be unavailable. In addition, there is possible boron toxicity (ILACO, 1989; Landon, 1985).

Most plants and soil micro-organisms thrive best in soils of pH 5 - 7.5. However, it must be recognised that plant species and even varieties may differ in the degree to which they favour or tolerate pH values beyond their range (Brady, 1974). In the next sections the toleration of the selected crops for soil pH is examined.

- **Barley**

Bland (1971) explains that as long as the pH is over 6.0 the barley can be grown successfully. Rayns (1959) suggested that it is safe to grow barley as low as pH 6.2. Mahmoud (1995) pointed out that barley is grown successfully in pH ranges between 6.5 and 7.8.

- **Wheat**

Landon (1985) states that the optimum pH for wheat is between pH 5-7. Gardner and Garner (1953) suggested that wheat can be grown on pH 5. They added that actual figures can vary according to the soil texture.

Alsgear (1983) claimed that the optimum pH for wheat in Libya is 6.5 – 7.5. These limits are widely supported by the reports of ARC trials in the east of Libya.

- **Maize**

According to the Agriculture Compendium, (1989), optimum pH range for maize growth is 5.5 – 7.5. Bland (1971) states that maize can be grown successfully in pH range 5.0 - 8.0. Similar margins are also indicated by the Maize Growing Manual (1982), Landon (1983), Purseglove (1985) and Berger (1962).

Bland (1971) claimed that for certain maize varieties a 100 % yield could be obtained in a pH range 4.0- 9.0 provided that there are no serious nutrient deficiencies, especially of micro-elements. According to Purseglove (1985), maize yields could decrease where pH values are less than 5.5. The optimum pH range of soils for maize growth is between 5.8 and 8.0. Beyond pH 5.0, toxicities of Aluminium (Al), Manganese (Mn), and iron (Fe) may occur, although maize is relatively more tolerant to levels of Al and Mn toxicity than other crops (Clark, 1982).

At high pH levels, nutritional problems with elements phosphorus (P), zinc (Zn), and iron (Fe) often occur especially in the pH range 7.4 – 8.0 (Clark, 1982). Chen and Barber (1990) find that with the increase of pH there was a decrease in P concentration in maize shoots and roots. The highest phosphorus (P) concentration was at pH 3.8 and the lowest phosphorus (P) at pH 8.3, both in shoots and roots. Also, the root length and surfaces were affected by low and high pH values. The largest root length and surface had developed at a pH value of 6.5.

Mahmoud (1995) confirmed these limits in Libyan soils. He states that the optimum range for maize is pH 6 – 7. These critical values were based on data and trials from the ARC in Libya.

- **Sorghum**

Landon (1985) states that the optimum pH for sorghum growth is between 5 – 8. Purseglove (1985) states that sorghum is tolerant of a wide range of soil conditions and pH for growth that is between pH 5 - 8.5. In conclusion, the threshold values of soil reaction for the selected crops were selected by comparing published data from around the world, especially semi-arid and arid regions. The information about pH was analysed together with data from trials by ARC in Libya and the threshold values were selected. Table 5.12 shows the threshold values of pH for the selected crops. These threshold values were based on the available information and ideally, field investigations should be conducted to confirm these limits.

Table 5. 10 Critical soil reaction limits between suitability classes (pH)

Crop	Highly Suitable S1	Moderately Suitable S2	Marginally Suitable S3	Not suitable Ns
Barley	8 – 6.5	< 6.5 – 5.5	< 5.5 - 5.3	< 5.3, > 8.0
Wheat	7.5 – 6.5	< 6.5 – 5.5	< 5.5 – 5	< 5 , > 7.5
Maize	7 – 6	< 6 – 5.5	< 5.5 – 5	< 5 , > 7.0
Sorghum	8 – 6	< 6 – 5.5	< 5.5 – 5	< 5 , > 8.0

Source: (developed by the author)

5-3-4 Nutrient Retention

5-3-4-1 Soil Organic Matter (SOM)

Soil organic matter increases the amount of water a soil can hold and the proportion of water available for plant growth. In addition, it is a major source of the plant nutrients phosphorus and sulphur, and the primary source of nitrogen for most the plants. Soil organic matter greatly influences the biology of the soil, because it provides most of the food for the community of heterotrophic soil organisms (Brady and Weil, 1999).

Brady and Weil (1999) suggest that evidence indicate that there are direct and indirect factors contributing to the favourable effects of organic matter on soil water availability.

It is well known that additions of organic matter e.g. manure and compost can improve soil properties. Brady and Weil (1999) state that the available moisture content of well drained soil containing 5 % organic matter is generally higher than that of a comparable soil with 3% organic matter. Kemper and Koch (1966) indicate that many soils in the western United States and Canada suffered a significant decline in the structural stability if soil organic carbon (SOC) was less than 2 %. Similarly Greenland *et. al.* (1975) conclude that with less than 2 % SOC soils were prone to structural deterioration in England and Wales. Allison (1973) summarises the role of SOM in crop production following four themes:

crop nutrition, micronutrient availability, soil available water, and cation exchange capacity.

There has been considerable controversy over the degree to which organic matter affects crop yield and whether its effect on available water capacity is a direct or indirect effect through soil structure and total pore space. Loveland and Webb (2003) conclude in their review that a soil's water-holding capacity (AWHC) at various suctions is influenced by SOM, but often only contributes <10 % to the known variance of this property, especially at high suctions. Hudson (1994) opposes this idea and states that the consensus view of the relationship between organic matter and AWHC is incorrect. His review of the literature suggested that many studies failed to demonstrate a relationship between organic matter and AWHC because they were not designed properly. Effects were masked by excessive variations in soil texture, stone content, and other properties that are known to affect AWHC. In order to minimise these variations, Hudson performed moisture retention analysis using different moisture retention values on several textural groups. The results showed that within all textural groups, as organic matter increases from 1 to 3 %, the AWHC approximately doubled. When it increased to 4 % it accounted for more than 60 % of the total AWHC in all three textural groups.

Crop productivity under dry land conditions is largely limited by soil water availability. Diaz-Zorita.*et.al.,* (1999) conducted a stepwise regression analysis between yields and soil properties and found different relationships in different years. In years when plants are drought-stressed, it appears that organic carbon and water retention content have a positive influence on crop yield. While in years where drought stress is absent, nitrogen and phosphorus availability appear to limit wheat production. They found that soil organic matter content positively affects soil water- holding capacity in the semi-arid Argentine

Pampas. In addition, wheat yield in all years of the study correlated linearly with the soil organic matter content in the top 20 cm. Grace *et.al.,* (1995) suggest that a gradual increase in grain yield from plots used continuously the growing wheat since the 1960s, is the result of a gradual build-up of the light fraction organic material, which assists in the maintenance of structure and nutrient availability. In their study the authors used data from permanent trials at the Waite Agriculture Research Institute in South Australia. Carter *et.al* (2002) state that SOM and aggregate stability are important indicators to assess sustainable land use. They added that total SOM influences soil compatibility, friability, and soil water-holding capacity.

The selection of critical limits for soil organic matter for crops poses several difficult problems (Arshad.*et.al*. 2002). Loveland and Webb (2003) state that a single critical threshold value for soil carbon content in temperate soils cannot be supported. In addition, they suggested that considerable quantitative investigation would be required to establish this clearly. However, crop manuals and some other publications suggest threshold values for some crops. Carter *et.al* (2002) explain in their paper that a critical limit for SOM at present is mainly established by consensus based on reference values derived from soil resource inventories.

There are many unpublished reports in the Agriculture Research Centre (ARC) in Libya which indicate guide lines for threshold values for the selected crops. These guide lines are based on past trials in some parts of the country where the ARC has branches. Selkhozpromexport (1980), Mahmoud (1995), and Kalogirou (2002) mention similar threshold values for the selected crops.

Table 5. 11 Suitability ratings for Soil Organic matter

Crop	Soil Organic Matter (%)			
	Highly Suitable (S1)	Moderately suitable (S2)	Marginally Suitable (S1)	Not Suitable (NS)
Barley, Wheat, Maize, Sorghum	> 1.5	1.5 - 1	<1- 0.5	< 0.5

Source: adapted from ARC (2002)

5-3-4-2 Cation Exchange Capacity (CEC)

Cation exchange characteristics play an important role in soils by determining the retention of any soluble fertilizer. Brady and Weil (1999) state that without cation exchange, the soil is not able to retain sufficient cation nutrients to support natural or introduced vegetation, especially following such events as cultivation or fire. They add that cation exchange and photosynthesis are fundamental life-supporting processes. Genon and Dufey (1991) suggest that the cation exchange capacity (CEC) is the most important soil chemical property with respect to mineral nutrient retention and bioavailability. CEC is also used as a reference in qualifying soil fertility standards.

Landon (1984) points out that CEC measurements are commonly made as part of an overall assessment of the potential fertility of a soil. Gao and Chang (1996) comment that soil CEC is important in plant nutrient uptake and ion movement and is highly correlated with organic carbon content and the clay content of soil.

The FAO (1979) quote CEC values of between 8 -10 me/100 g of soil as indicative minimum values in the top 30 cm of soil for satisfactory production under irrigation, provided that other factors are favourable. They add that any

CEC value of < 4 me/100g soil indicates a degree of infertility unsuitable for irrigated agriculture.

Yeha (1982) explains that soil with a CEC < 4 me/ 100g soil is unsuitable for irrigated agriculture. He adds that the CEC values of > 16 me/ 100g soil can be considered as highly suitable for irrigated field crops. Similar claims were made by Selkhozpromexport (1980) in the study of the eastern zone of Libya. Mahmod (1995) confirmed these figures for the field crops. These threshold values were found to be in agreement with the figures introduced by FAO.

The threshold values were selected by carefully comparing the local limits with the FAO limits (Table 5.12).

Table 5. 12 Soil CEC suitability ratings in the study area

Crop	Highly Suitable (S1)	Moderately suitable (S2)	Marginally Suitable (S3)	Not Suitable (NS)
Barley and Sorghum	> 16 me/100g	>8–16 me/100g	5–8 me/100g	< 5 me/ 100g
Wheat and Maize	> 24 me/100 g	>16- 24 me/100 g	16-8 me/100 g	< 8 me/100 g

5-3-5 Excess of Salts

5-3-5-1 Soil Salinity

Soil salinity is a serious problem in arid and semi-arid zones of the world where poor-quality water is often the only source available for irrigation. Salts tend to accumulate in the upper soil profile, especially when intense evapotranspiration is associated with insufficient leaching. The addition of salts to the soil alters its physical and chemical properties, including soil structure and hydraulic conductivity (Mass, 1996; Tanji, 1996).

Soil salinity occurs where the supply of salts, for example from rock weathering, capillary rise, rainfall or flooding, exceeds their removal (Landon, 1984). In almost all semi-arid irrigated cropland, non-irrigated crop land and rangeland, salt build-up is an existing and/or potential danger. Libya is potentially at risk of soil salinity. Selkhozpromexport (1980) and Mahmoud (1995) state that 23% of the eastern region of Libya is affected by saline soils, including the study area for this research.

Salinity affects plants through inhibiting the uptake of water by osmosis. Moderate salinity levels retard growth and reduce yield, while high levels kill crops and may cause areas to be barren of plants. Salinity can affect plant growth by reducing the amount of water available to the crop and by increasing the concentration of certain ions that have a toxic effect on plant metabolism (FAO, 1995).

The extent of the adverse effect of soil salinity on plant growth varies with the crop being grown. Crops respond to salinity in different ways; some crops can produce an acceptable yield at much greater soil salinity than others. This is because some are better able to make the needed osmotic adjustments to enable them to extract more water from saline soil (FAO, 1985; Hillel, 2000). Among the crops that are considered salt tolerant are barley, sugar beet, table beet, asparagus, spinach, tomato, cotton, dates and Bermuda grass. Crops that are known to be sensitive to salinity are radish, celery, beans, clover and nearly all fruits (Hillel, 2000).

Plant salt tolerance or resistance is generally thought of in terms of the inherent ability of the plant to withstand the effects of high salts in the root zone or on the plant's leaves without a significant adverse effect. In terms of its measurement, salt tolerance is described as a complex function of yield decline across a range of salt concentrations (Maas and Hoffman, 1977). Salt tolerance can be adequately measured on the basis of two parameters: (a) the threshold at which the electrical conductivity that is expected to cause the initial significant reduction in the maximum expected yield, and (b) the slope of the relationship between salinity and relative yield (Figure 5.2). The slope is simply the percentage reduction of yield for each unit of added salinity above the threshold value. Relative yield (Y) at any salinity exceeding EC_t can therefore be calculated:

$Y = 100\ S\ (EC_e - Ec_t)$ **Equation 5. 1**

Where $EC_e > Ec_t$

S = the slope expressed in percent per dS/m

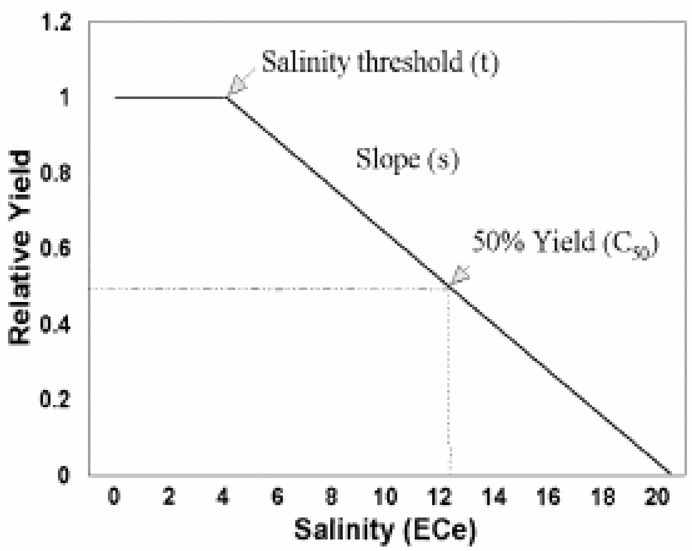


Figure 5. 2 Salt tolerance parameters relating relative yield to increasing salinity in the root zone

It is widely accepted that plant growth rates decrease linearly as salinity increases above the critical salinity threshold at which the growth rate first begins to decrease (Mass and Hoffman, 1977; Maas, 1990).

Yeha (1982) claims that results from Libyan studies were in agreement with threshold values reported from the Maas and Hoffman equation. These thresholds values were used by the Agriculture Research Centre in Libya. As a result the threshold values for the crop tolerance for the selected crops in the study area were calculated with the method explained in FAO (1985). Table 5.13 show the critical limits between suitability classes for each crop. Barley is the most salt tolerant of the four crops (Landon, 1984; Purseglove, 1985; Stoskopf, 1985).

Table 5. 13 Salt Tolerance of selected crops

Crop	S1	S2	S3	Ns
Barley	0 - 8	> 8 -10	>10 -13	>13
Wheat	0 -6	> 6 -7.4	> 7.4 - 9.5	> 9.5
Maize	0 -1.7	> 1.7 -2.5	> 2.5 – 3.7	> 3.7
Sorghum	0 – 6.8	> 6.8 – 8.4	> 8.4 -10	> 10

Source: Adapted from FAO (1985)

5-3-5-2 Soil Alkalinity (Sodicity)

Most temperate agricultural soils contain clay particles, the surfaces of which are saturated with calcium ions. Such soils are stable in water because calcium-saturated clays disperse less in water but tend to remain flocculated. However, in arid and semi-arid climatic regions and in areas where saline water is used for irrigation, some of the calcium ions can be displaced and replaced by sodium ions. Sodic soils are those which have an exchangeable sodium percentage (ESP) of more than 15. Excess exchangeable sodium has an adverse effect on the physical and nutritional properties of the soil, with consequent reduction in crop growth, significantly or entirely.

Sodicity is determined by the exchangeable sodium percentage (ESP). ESP is the amount of adsorbed sodium on the soil exchange complex expressed as a percent of the cation exchange capacity in milliequivalents per 100 g of soil. Thus,

$$ESP = \frac{\text{Exchangeable sodium (me/100g soil)}}{\text{CEC}} \times 100$$ **Equation 5. 2**

When more than 15% of the adsorbed ions are sodium, the soil is described as sodic (FAO, 1983; 1979). Sodic soils exhibit large shrinkage and swelling as they become wet and dry. They are completely structureless and homogeneous and as such represent the extreme case of physical degradation. In sodic soils sodium ions are attached to clay particles. The monovalency of sodium cations leads to a loss in stickiness of clay particles when wet. Indeed, if the proportion of divalent ions is reduced, the aggregate formation will also be reduced. This leads to collapsed and unstable soils that become impermeable to water and roots and which erode easily (Tanji, 1996; ILACO, 1989; Landon, 1984).

The FAO (1988) conclude that plant growth is adversely affected in sodic soils due to one or more of the following factors: firstly, high ESP in sodic soils influences markedly the physical soil properties. As ESP increases, so the soil tends to become more dispersed which results in the breakdown of soil aggregates and this lowers the permeability of the soil to air and water. Dispersion also leads to the formation of dense, impermeable surface crusts that hinder the emergence of seedlings. Secondly, the effect of ESP on plant growth is through its effect on soil pH. A high pH on sodic soils has no direct adverse effect on plant growth by itself. However, it frequently results in lowering the availability of some essential plant nutrients such as Calcium, Magnesium, phosphorus, iron, manganese and zinc. Thirdly, accumulation of certain elements in plants at toxic levels may result in plant injury or reduced growth and even death (specific ion effects). Elements more commonly toxic in sodic soils include sodium, molybdenum and boron.

Landon (1984) points out that sodicity has two distinct main effects on crops: firstly through direct toxicity of the sodium ion and secondly by giving rise to massive or coarse columnar soil structure and low permeability. The second effect is much worst if a high ESP is combined with a low level of soluble salts. Similar observation and claims were made by ILACO (1989).

Sodicity is common in semi-arid areas, particularly in sites where incoming water containing dissolved salt is lost by evaporation. Parent material is sometimes very important in determining the exchangeable sodium and salt levels, with marine deposits being particularly liable to have high values (FAO, 1983; Landon, 1984). Although sodicity and salinity can be distinguished, a saline soil can be transformed to a sodic soil by the leaching of calcium ions during rain or irrigation.

Wright and Rajper (2000) observed two wheat varieties which were grown in artificially-created sodic soils in pots at a range of sodicity levels (ESP 15-52). They suggest that at an ESP up to 40-50, adverse physical characteristics are the major cause of low wheat yield in sodic soils, either due to their direct effects in decreasing growth, or their indirect effects in increasing the uptake of Na^+ and decreasing the uptake of K^+. They explained that above ESP 50, roots are less able to exclude Na^+, even in the presence of improved physical soil conditions, so that at these sodicity levels, both adverse physical and adverse chemical properties contribute to the decreased yield. Nuttall *et. al*., (2003) suggest that soil salinity, sodicity, and high extractable boron (B) reduced wheat yields on alkaline soils of south-eastern Australia. They found that a subsoil needs to have an ECe < 8 dS/m and ESP < 19% for crops to make use of water deep in the profile.

Marlet *et. al*., (1998) explained that the use of the resulting non-saline sodic soils pH 8.5-9.8, ECs = 2.2-3.2 dS/m, exchangeable sodium percentage (ESP) = 5 – 40 is greatly limited because of the alkalinity and sodicity in Niger. They suggested that a subsoil threshold effect is observed for an ESP 10 or a pH 8.5 and the hydraulic conductivity becomes very low.

Sodicity should be rated according to the overall effect on crop production. Plants vary considerably in their ability to tolerate sodium ions. Most annual crops are less sensitive, but may be affected by higher concentrations (Yeha, 1982; FAO, 1983; Landon, 1984; Yeha, 1982). Landon (1984) confirmed that crops have different tolerances to the presence of exchangeable Sodium (Table 5.14)

Table 5. 14 Tolerance of various crops to ESP under non-saline conditions

Tolerance to ESP	ESP threshold values	Crop
Extremely sensitive	2 – 10	Deciduous fruits, Nuts, Citrus, Avocado Mill
Sensitive	>10 – 20	Beans
Moderately tolerant	>20 – 40	Clover, Oats, Tall fescue, Rice, Dallis grass, Poir
Tolerant	>40 – 50	Wheat, Cotton, Alfalfa
Most tolerant	> 50	Crested and Fairway Wheatgrass, Host, Beau, Rhodes grass, Kunth

Source: (Landon, 1984)

Plant growth is adversely affected due to a combination of two or more of the above-mentioned factors (FAO ,1988), depending on the level of exchangeable sodium, nature of the crops and the over-all level of management. It is generally recognised that an ESP of 15 is a limit above which the soils are characterized as sodic. This limit has been increasingly found to be useful because many soils show sharp physical property deterioration around and above this value. FAO (1988) classified the sodicity hazard on the basis of the ESP (see Table 5.15).

Table 5. 15 Exchangeable sodium percentage (ESP) and sodicity hazard

<table>
<tr><th>Approx. ESP</th><th>Sodicity hazard</th><th>Remarks</th></tr>
<tr><td>< 15</td><td>None to slight</td><td rowspan="5">The adverse effect of exchangeable sodium on the growth and yield of crops in various classes occurs according to the relative crop tolerance to excess sodicity. Whereas the growth and yield of only sensitive crops are affected at ESP levels below 15, only extremely tolerant native grasses grow at ESP above 70 to 80.</td></tr>
<tr><td>15 - 30</td><td>Slight to moderate</td></tr>
<tr><td>>30 - 50</td><td>Moderate to high</td></tr>
<tr><td>> 50 - 70</td><td>High to very high</td></tr>
<tr><td>> 70</td><td>Extremely high</td></tr>
</table>

Source: (FAO, 1988)

Yeha (1982) classified the plants in Libya into five categories according to ESP tolerance. The classification was based on the USDA classification.

Mahmoud (1995) points out to the fact that ESP in some Entisols in the south of Libya have been found to be between 3.1 – 28 per cent. Mahmoud believes that the main reason for this high ESP is not the high sodium, but the low CEC in these sandy soils. He argues that the CEC is very low and ranges from 1- 10 me/100 g soil. Therefore, the crops in such soils may not be affected by the sodium even thought the ESP appears to be high. This could be true in the south of the country and some parts of the North West, however, in the study area, on the North East of Libya, the CEC is relatively higher.

The selection of the threshold values for the selected crop in the study area was based on the publication of ARC (1975, 1985) in Libya. (These figures are widely quoted by Selkhozpromexport, 1980; Yeha, 1982; Sasi, 1988; Mahmoud, 1995). Table 5.16 shows the threshold values for the selected crops.

Table 5. 16 Suitability ratings of ESP for selected crops

Crop	S1	S2	S3	Ns
Barley	0-15	>15-25	>25- 50	> 50
Wheat	0-10	>10-25	>25-35	> 35
Maize	0-8	>8-15	>15-25	> 25
Sorghum	0-10	>10-20	>20-30	> 30

Source: complied by the author

5-3-6 Soil Toxicities (Calcium Carbonate)

Calcium carbonate ($CaCO_3$) in the form of free lime in the soil profile affects soil structure and interferes with infiltration and the evapo-transpiration process. It influences both the soil moisture regime and availability of nutrients (FAO, 2002). Carbonates in soil profiles may be derived from carbonate-rich rocks but are more commonly encountered as a secondary deposition from groundwater (Landon, 1984).

Calcium carbonate being only slowly soluble, does not affect plants at the percentage levels at which soluble salts become harmful, but may have adverse effects when present in high concentrations, including as calcrete horizons. This is most likely to occur in semi-arid regions (ILACO, 1989).

Carbonates may originate from calcareous materials or may have accumulated in a particular soil horizon through pedogenetic processes. In the latter case the name calcic horizon is used, provided that the layer thickness is 15 cm, has a calcium carbonate equivalent content of 15% or more and a calcium-carbonate content that is at least 5% higher than the C horizon. Soft and hard concretions may be formed. The hard concretions may grow into a continuous Peterocalcic horizon. This prevents the plant from growing and an excess of calcium ions adversely affects the uptake of various other ions (ILACO, 1989).

High levels of carbonate affect the physical, as well as the chemical properties of a soil. According to Massoud (1973) the available moisture capacity remains low irrespective of the measured clay content. Landon (1984) explains that a significant amount of free carbonate in a soil causes other essential nutrients to be less available, particularly if they are of relatively limited supply.

Landon (1984) states that there is no precise rating for levels of free carbonate, but values of over about 40 % can be considered as extremely calcareous.

A calcium carbonate % equivalent of > 15 % is used in the FAO definition of a calcic horizon and 40 % for the calcareous material underlying rendzina soils. Selkhozpromexport (1980) states that soil of calcium carbonate more than 40 % limited the yield to 20-15 % in Libyan conditions. Table 5.17 show the threshold values of Carbonate in the study area based on the data from ARC experiments in AL Fateh. The data shows that wheat and barley can be grown successfully in soils with $CaCo_3$ % less than 20 % whereas maize can be grown in soil with CaCo3 % less than 15 %. Kalogirou (2002) states similar threshold values for barley, wheat and maize in the land suitability classification for Greece.

Table 5. 17 Threshold values of suitability classes of calcium carbonate %

Selected Crops	S1	S2	S3	Ns
Barley	0- 20	>20- 30	>30 -40	>40
Wheat	0- 20	>20- 30	>30 -40	>40
Maize	0 -15	>15 -20	>20 – 35	> 35
Sorghum	0 -15	>15 -20	>20 – 35	> 35

Compiled by the author

5-3-7 Infiltration Rate

Infiltration refers to the entry of water into soil. Infiltration problems occur if irrigation water does not enter the soil rapidly enough during the normal irrigation cycle to replenish the soil with water needed by the crop before the next irrigation. The infiltration rate can be affected by many factors such as water quality, soil texture, clay minerals and cation exchangeable capacity. FAO (1985) states that an infiltration rate as low as 3 mm h^{-1} is considered low, while a rate above 12 mm h^{-1} is relatively high.

Infiltration rates are vital in defining the irrigation method in a soil. Landon (1984) states that optimum basic infiltration rates for surface irrigation are considered to be in the range of 7 to 35 mm h^{-1}. He introduced a classification for soil infiltration rate categories . When basic infiltration rates become faster than 35 mm h^{-1}, soils are considered increasingly unsuitable for surface irrigation, and the overhead method becomes preferable. This is the result of poor uniformity of applications, deep percolation losses excessive leaching of crop nutrients and low irrigation efficiency (Landon, 1984). FAO (1979) quotes 12.5 mm h^{-1} as the upper limit for gravity irrigation except in small basins. Landon (1984) mentions that soil infiltration rates from 10 to 20 mm h^{-1} can be classified as marginal infiltration rate.

The infiltration rate depends on soil texture (the size of the soil particles) and soil structure and is a useful way of categorizing soils from an irrigation point of view (FAO, 1990). Table 5.20 shows the infiltration rates for some soil types.

Table 5. 18 Basic infiltration rates for various soil types

Textural Classes	Basic infiltration rate (mm h^{-1})
Sand	less than 30
Sandy loam	20 - 30
Loam	10 - 20
Clay loam	5 - 10
Clay	1 - 5

Source: (FAO, 1990)

Selkhozpromexport (1980) investigated the infiltration rate in the North East of Libya and classified the infiltration rate in the study area. Selkhozpromexport (1980) states that an infiltration rate of 8-12 mm hr^{-1} is an optimal rate whereas an infiltration rate of less than 6 mm hr^{-1} is low. FAO (1990) states that sprinkler irrigation is best suited to sandy soils with high infiltration rates, although they are adaptable to most soils. There are many different figures quoted in different unpublished reports in ARC in Libya concerning the infiltration rate threshold values for sprinkler irrigation. These reports were in agreement with the figures quoted by Selkhozpromexport (1980). Table 5.19 shows the threshold values for suitability classes for the selected crops. However, these figures need more investigation to provide an accurate threshold values.

Table 5. 19 Suitability ratings for infiltration rate in the study area

Crop	Highly Suitable	Moderately suitable	Marginally Suitable	Not Suitable
Selected Crops	>12 mm h^{-1}	>8-12 mm h^{-1}	6-8 mm h^{-1}	< 6 mm h^{-1}

Source: Compiled by the author

5-3-8 Conditions for Germination

Surface stoniness can impede cultivation and harvesting as well as seed germination and establishment. Even if the surface stones are cleared, subsequent cultivation may bring buried stones to the soil surface. The presence of the stones affects soil workability and reduces available water-holding capacity. In addition, sub-surface stoniness reduces water-holding capacity and increases infiltration rates. It is assumed that a level of more than 40 per cent of coarse materials by volum will markedly influence the water-balance in the soil profile (Sys and Riquier, 1980).

The gravel content of soil profiles has different effects on crops depending on soil texture. According to the Agriculture Compendium (1989), a gravel content up to 15 % is classified as a very good soil condition. Gravel content between 15-35 % is classed as good soil condition up to 80 cm soil depth.

According to Babalola and Lal (1977), gravel concentrations above 20 % significantly reduce rate of root elongation, root volume, the number of roots and depth of root penetration. They also claim that root development is generally improved when gravel concentration is less than 10 %. The average rate of root penetration in the gravely horizon was 1.6 cm/ day whereas in the surface soil it was 3 cm/day.

The publications from ARC in Libya indicated that the stones and gravel on the surface should be less than 3 % in the irrigated cereal crops. In addition, when the stones and gravel exceed 20 % the land becomes unsuitable for irrigation (ARC, 2002).

Table 5. 20 Classes for Assessment of condition for germinations (stones %)

Crop	Highly Suitable	Moderately suitable	Marginally Suitable	Not Suitable
Selected crops	0-3	> 3-9	> 9-20	> 20

5-3-9 Oxygen Availability to the roots (Soil Drainage)

Excessive water in the soil reduces the exchange of air between soil and atmosphere. Therefore, wet soil conditions are generally accompanied by oxygen deficiency. This deficiency causes reductions in root respiration and total root volume, increased resistance to the transport of water and nutrients through the roots, and formation of toxic compounds in soils and plants. Wanner and Schmucki (1950) point out that under anaerobic conditions micro-organisms produce compounds like sulphides and butyric acid that are extremely toxic to plant growth. Practically all roots of non aquatic plants are injured if the soil is allowed to remain waterlogged (Harris and Van Bavel, 1957; Skaggs and Schilfgaarde, 1999). Figure 5-3 shows the processes leading to a reduction in plant growth and yields due to excessive soil water.

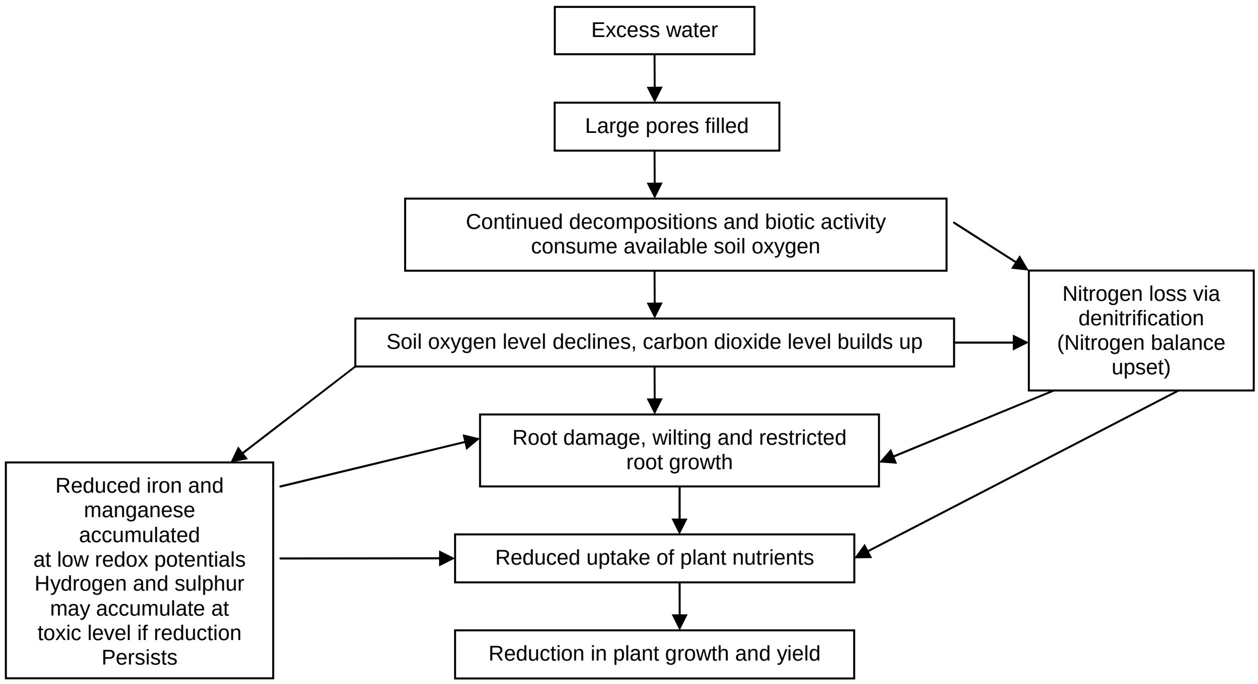


Figure 5. 3 Processes leading to reduction in plant growth and yields due to excessive soil water

Source: (Skaggs and Schilfgaarde, 1999)

Plant roots require oxygen for respiration and consume a large amount of oxygen and at an average 25° C they consume about nine times their volume of oxygen gas each day (FAO, 1985). Crops other than rice must obtain their oxygen through the soil. Thus an adequate supply of oxygen in the soil throughout the season is a requirement for many crops (FAO, 1985).

The responses of crops to poor aeration resulting from waterlogged soil conditions are many. Skaggs and Schilfgaarde (1999) reported that the response in a reduction of seed germination, root function, general growth and development, and shoot growth and development. Harris and van Bavel (1957) conclude that respiration is the most sensitive aspect of plant activity with regard to soil aeration and that reduction in respiratory activity is the first step in the growth-limiting effect of insufficient aeration.

Drainage of irrigated lands is one of the requirements for sustaining agricultural productivity in a given region over the long term. Adequate drainage allows for better aeration in the crop root zone and also provides a means by which salinity and toxic elements can be managed and controlled (Skaggs and Schilfgaarde, 1999).

Although deficient aeration can be readily detected in soils from standard soil survey observations, such as gley colours, there is no measurable property of soil, or reliable instrument, for determining soil aeration status (FAO, 1985).

There are a number of different methods which may used to characterise aeration conditions in soils. These methods have been described (Schilfgaarde, 1974; Skaggs and Schilfgaarde, 1999).

FAO (1983) list five methods for the assessment for oxygen availability: (1) measurement of continuous periods with redox potential (Eh) below 200 mV; (2) measurement of continuous period of water saturation; (3) colour and mottling of soil; (4) soil drainage class and (5) vegetation. It is recommended by FAO that soil drainage classes, should be used .This incorporates soil colour and mottling, preferably supported by some estimate of periods of water saturation by monitoring groundwater levels over different parts of the growing season. The use of soil drainage class alone can be misleading, as colour and mottling are always indicative of the current seasonal water status of the soil. It is possible to rate oxygen availability on a modelling basis. As yet, however, specific yield response factors have not been identified.

The most suitable method to be used in the study area is to assess the oxygen availability based on the data available. From a review of data available, the classification of soil drainage classes is based on the hydraulic conductivity (Mahmod, 1995). Table 5-21 shows the soil drainage classes. There are data available about the hydraulic conductivity of the soil pits in the study. These data can be used in the classification of soil drainage classes and thereafter, as suitability classes for crops.

Landon (1984) states that the ideal soils to produce maize, wheat, and sorghum are well-drained soils. Purseglove (1985) states that barley, wheat, maize, and sorghum can be grown on a wide variety of soils, but they perform best on well-drained land. Similar claims have been made by Gibbon & Pain (1985), Mahajan (1972), Mahmod (1995), Rasmusson (1985), Stewart and Nielson (1990) Arnon (1972a), Arnon (1972b), Bland (1971) and Doggett (1988).

Hydraulic conductivity (K) of a soil is its conductivity to the movement of water down a pressure gradient. High values of K are associated with well-structured soil and continuous large pores; they allow high infiltration rates and rapid drainage (Barley 1959). Hydraulic conductivity varies with soil type and management. K values below 10 mm/h are low and likely to cause run off following rainfall or problems with irrigation, given that steady rain falls at about 10 mm/h. K values of 10 to 20 mm/h can give intermittent runoff (a downpour falls at about 50 mm/h) while values up to 120 mm/h are associated with occasional, increasingly rare run off. Values above 120 mm/h may facilitate regular drainage to the groundwater, causing potential problems for heavily-fertilized soils, and those treated with effluent, herbicides or pesticides (FAO, 1995).

There have been many attempts to develop a drainage classification for Libyan soils. One classification is linked to hydraulic conductivity. The classification is based on tests and experience in different parts of north Libya. The threshold values for the land suitability classes were selected based on classification by the ARC in Libya. Table 5.21 show the drainage classification based on hydraulic conductivity.

Table 5. 21 Soil drainage classes and hydraulic conductivity

Drainage class	Hydraulic conductivity ($mm\ hr^{-1}$)	Suitability classes for the selected crops
Excess	> 125	NS
Well	>42-125	S1
Moderate	>16.6-42	S2
Imperfect	>4-16.6	S3
Poor	0.4- 4	NS
V Poor	< 0.4	NS

Source: Compiled by the author

5-4 Erosion Criteria (Erosion Hazard)

The effect of erosion on crop productivity has been recognised and studied for about 50 years. However, erosion productivity relationships are still not well understood (National Soil Erosion- Soil Productivity Research Planning Committee, 1981).

Soil erosion leads to a reduction in soil quality and productivity and hence crop yield. The extent to which crop yield responds to soil erosion depends on several variables such as crop type, soil properties, management practices and climate characteristics. Erosion often results in a decrease of the soil supply functions in three several ways, by (1) the removal of organic matter; (2) the change in depth to a possible root-barrier; and (3) the loss of structure and increased compaction (Bakker *et al*, 2004)

The three main factors reported in pervious studies that are thought to be responsible for crop yield reduction are (a) root growth hindrance by clayey subsoil or by a pan or bedrock, (b) water deficit and (c) nutrient deficit. Some other literature also notes other limiting factors such as soil temperature, pH and aeration (Larney *et al*, 1995; Mielke and Schepers, 1985; Mohkma and Sietz, 1992), but these are never reported as being the dominant control on crop yield reduction due to erosion. The relationships between the erosion processes and the main factors are described briefly below.

If crop growth is sensitive to drought, then it is likely that water deficit following erosion will become a factor behind yield reduction. With topsoil removal, water availability is affected by three processes: (a) soil depth decrease, reducing soil water storage capacity; (b) loss of soil structure due to reduction in organic matter and increased compaction, which reduces the soil water holding capacity (Daiz-Zorita *et al*, 1999; Larson *et al*, 1985); (c) the exposure of more clayey soil material at the surface, which has a detrimental effect on the extent to which soil moisture is available to plants. Topsoil removal may often result in a nutrient deficit. In the absence of sufficient fertilizer application, a shortage of nutrients will cause a rapid decline in crops yield.

If the top soil clay content increases because of erosion, nutrients may still become a factor of yield reduction when the fertilizer is applied. Nutrients are often strongly absorbed on to clay particles, which can lead to reduced nutrient availability (Rhoton and Lindbo, 1997).

Erosion may also cause physical hindrance to root growth, for example, when a clayey subsoil is present. Physical hindrance to root growth starts as soon as a significant part of the root system encounters the restricting horizon. Where growth is hindered by bedrock or a pan, yields will rapidly approach zero once the minimum soil requirements for rooting are exceeded by soil removal (National Soil Erosion – Soil Productivity Research Planning Committee, 1981).

According to Sevink (1988), accelerated soil erosion is a serious problem in the Mediterranean region. Climatic characteristics of the Mediterranean region include rare freezing; hot summers with at least two to three dry months and cool rainy winters; precipitation often falls as storms of high intensity which produce torrential runoff (Bradbury, 1981). Because of these violent storms, the Mediterranean climate is described as one of the most aggressive in respect of erosion. Also, in regions such as the southern Mediterranean, cracks can form by desiccation during dry summers, causing extreme dissection of the slopes.

A major problem in the climate in this region is that the winter rainfall, which causes erosion, does not coincide with the vegetation cover that protects the soil surface, especially in cultivated cropland and heavily grazed pasture. The Mediterranean climates do not favour the development of a dense vegetation cover on most slopes, which are poorly stabilised at ground level. As a result, areas with Mediterranean type climates are traditionally classified as areas with high potential erosion rates (Vita-Finzi, 1959; Saunders and Young, 1983; Brown, 1990)

In the study area, where the environment is vulnerable, the variability of rainfall and the occurrence of occasional relatively-heavy showers characterised by high intensity can produce run off. The removal of natural vegetation from the land surface is the main factors that accelerate soil erosion. The combination of these factors in addition to the topography has increased the rate of soil erosion by water in this area.

There have been some studies dealing with the influence of soil on agriculture potential, but the problem of soil erosion is mentioned only briefly in some pilot studies. However, there have been two major studies in Libya and on the study area. The first was a report by FAO (1959) made by a team of experts using the available information on water resources to advise on measures for development of water resources and water conservation in northern Cyrenaica (north-east of Libya).

The second study was conducted by Selkhozpromexport (1980). It concluded that the north-east of Libya is subject to severe erosion. The most affected area represents 70.7 % of the north-east. Selkhozpromexport (1980) distinguished two types of accelerated erosion: water erosion and wind erosion. Water erosion is common in the form of sheet washing, occurring mainly within the Jabal Akhdar Upland while wind erosion is found in the form of deflation within the littoral plain (Selkhozpromexport, 1980; Mahmoud, 1995). Table (5-22) shows the size of the problem in Libya and especially in the study area.

The FAO (1976, 1983) list erosion hazard as a land quality which should be included in land evaluation. The objective of erosion hazard assessment is to identify those areas of land where the maximum sustained productivity from land use is threatened by excessive soil loss (Morgan, 1995).

The FAO (1983) state that the most satisfactory methods of erosion hazard assessment are based on predicted soil losses by modelling the determinants of climate, soil erodibility, slope, and vegetation factors. Detailed steps are given in the FAO documents to rate the suitability for erosion hazard whichever method or model is used for calculation of estimated soil losses (FAO, 1983).

Table 5. 22 Water erosion in Libya

Erosion Type	Area (1000 ha)	
	North West Region	North East Region
Sheet Erosion		
Slight	155.5	241.7
Moderate	154.5	41.7
Severe	54.5	1.7
Gully Erosion		
Slight	85.3	0.8
Moderate	73.0	0.0
Severe	57.0	0.0
Total Erosion	511	285.7

Source: (Selkhozpromexport, 1980; Mahmoud and Sluman, 1988)

Rates of soil erosion vary across the landscape and even within a small field. Climate variability and changes in land use also cause these rates to vary over time. Therefore direct measurement of soil erosion is always problematic. Consequently, the magnitude of erosion, the areas of excessive erosion and the projection of long-term changes in crop production caused by soil erosion, can often only be estimated (Foster, 1988).

Prediction methods of soil erosion were described by Foster (1988) as a package of scientific knowledge that effectively transfers technology from the researcher to the user. A model is a method of predicting soil loss under a wide range of conditions (Morgan, 1985). Three types of models can be identified: black box, grey box and white box.

Most of the models used in soil erosion studies are the empirical grey-box type. They are based on defining the most important factors and the thorough use of observation, measurement, experiments, and statistical techniques, relating them to soil losses (Morgan, 1995).

In recent years significant advances have been made in the understanding of the mechanics of erosion. As a result greater emphasis is being placed on developing white-box and physically-based models. Hudson (1995) classifies the models into four different models: empirical or black-box models; process-based or physically based models; productivity models and watershed models. A description of the models and their theoretical background can be found in Morgan (1995) and Hudson (1995).

The Universal Soil Loss Equation (USLE) is the most widely known erosion model. Originally developed in USA to predict long term average annual erosion under various types of crop management system, it has been widely used elsewhere. The USLE is an empirical model developed from analysis of more than 10,000 plot-years of runoff and soil loss data from small plots scattered through the USA (Wischmeier and Smith, 1971; 1978). More process-based hillslope models have been developed since then.

WEPP (Water Erosion Prediction Project) is a process-oriented model, based on modern hydrological and erosion science, designed to replace USLE for the routine assessment of soil erosion by organisations involved in soil and water conservation and environmental planning and assessment.

EUROSEM (European Soil Erosion Model) is an example of the European effort to develop more process-based models of rainfall erosion (Quinton and Rickson, 1994; Morgan, 1995). However, these process-based models have data and computer requirements that cause difficulties when efforts are made to apply them beyond the small catchment scale. Data constraints mean that, for practical purposes, the USLE provides the basis for modelling rainfall erosion in catchments (Kinnell, 1998).

Hudson (1995) and Morgan (1995) stressed the importance of identifying the exact objectives and purpose of the model which are designed to estimate soils erosion (Wischmeier and Smith, 1971; 1978). Morgan (1995) further clarifies this by stating that when selecting a model, care needs to be taken to avoid misuse by applying it to conditions beyond those of the database from which it was derived, and data being attracted to sophisticated schemes for which data input is difficult to obtain or which have not been properly validated. Despite the present state of development in physical-based models, a simple empirical models is often more successful in predicting soil erosion than a complex physically-based one which is difficult to operate and has been only partially evaluated (Morgan, 1995).

The USLE model is a statistical model and is a relatively simple erosion model, which is easy to parameterise and thus requires less data. Integrating the model with GIS facilitates data manipulation, data input and output display. Most importantly, GIS spatial display and analysis utilities allow the USLE model to be applied to individual raster cells. Another advantage of the GIS USLE approach is its ability to predict soil loss over large areas due to the interpolation capabilities of GIS (Lufafa *et al*., 2003).

The USLE and GIS have been used in Kenya to map and quantify soil erosion to help plan soil conversation strategies at the regional level (Mati *et al*, 2000). The study shows that in a GIS environment the USLE can be applied to determine field-scale soil loss both quantitatively and spatially, and to predict erosion hazard over large watersheds.

In the Kenyan study, the soil loss values estimated by the USLE were considered realistic after comparison with plot data, reconnaissance surveys and sediment yield from the major river in the basin (Mati *et al*, 2000). Fistikoglu and Harmancioglu (2002) concluded that the result of the study shows that GIS permits more effective and accurate application of the USLE model for small watersheds provided that sufficient spatial data are available. In this study the USLE and GIS used to assess the erosion hazard in the study area.

- **Tolerable soil loss rates (T)**

The tolerable soil loss (T) has been defined (McCormack and Young, 1981) as the maximum level of soil erosion that will permit a high level of crop productivity to be maintained economically and indefinitely. The T-value is operationally defined in terms of the long-term averaged annual soil losses estimated with the USLE and is normally applicable to the agriculture field. It is a value based on renewal due to soil formation rates, as well as replenishment of fertility from added organic matter. Guide values of T have been developed in the USA which has been adopted by many other researches for the assessment of erosion hazard.

Knowledge of the T-value for a particular soil is important in the application of the USLE. The maximum T-value of 11.2 t ha^{-1} yr^{-1} (McCormack and Young ,1981) was adopted in the USA for permeable medium-textured soils in well managed cropland where the A horizon is estimated to develop at about this rate. This rate of soil formation is much faster than the rate at which parent materials weather to form soil.

In the semi-arid and arid environment of Libya the soil formation rate is at a lower rate than those in temperate regions. In Kenya, Dunne *et al,* (1978) estimated soil formation rates of 0.125 t ha^{-1} yr^{-1} with 0.18- 0.3 t ha^{-1} yr^{-1} for the humid areas. Barber (1982) observed that in Kenya, the T-value would have to be lower than those in USA and that even with a T-value of 6.7 ton ha^{-1} yr^{-1}, soil depth will still be lowered.

Bertoni. et al, (1958) suggest that the tolerable rate of erosion is less than 4.5 t ha^{-1} yr^{-1} in Brazil. Lal (1976) states that the soil loss which can be tolerated in south west Nigeria ranged from 0.05 - 2 ton ha^{-1} yr^{-1}.

G.E.F.L.E (1975) suggest that tolerable soil loss in the Gebel Akhdar ranges from 2.5 to 5 ton ha^{-1} yr^{-1}. Similar values are quoted by G.E.F.L.E in Tunisia. Murad (1997) states that soil loss in the Hamama region in the Gebel Akhdar were 1.62 and 4.14 t ha^{-1} yr^{-1} for the first year and second years of his study, respectively.

Results from the study area of this reserach and similar regions indicate that soil loss is less than 2.5 ton ha^{-1} yr^{-1}. When the soil loss rate exceeds this value the soil crop yield decreases. Selkhozpromexport (1980) confirmed these figures. These figures derived from previous plots observed in the study area.

Table 5.23 shows the suitability ratings for soil loss. However, these figures should be used with caution. There is a need for further work in the study area to confirm these figures or to reach accurate values.

Table 5. 23 Suitability classes for erosion hazard

Suitability Classes	Potential Soil Loss (ton h^{-1} yr^{-1})
S1	0- 2
S2	>2 - 5
S3	>5 - 7
NS	> 7

5-5 Topographic Criteria (Slope)

Topography is often a major factor in irrigation evaluation. It influences the irrigation method, drainage, erosion, labour requirements, irrigation efficiency, and the cost of land development (FAO, 1979). The dominant topographical factor governing the suitability of an area for sprinkler irrigation is the terrain slope. Permissible slopes for irrigation depend on the type of irrigation systems and assumed level of inputs and management (FAO, 2002).

Sprinkler systems can be used to some extent on steeper slopes compared to gravity systems. However, some large central pivot systems can be only used on flat or almost flat terrain. For some other sprinkler systems, they may be used on slope up to 24 %. However, for annual crops, serious erosion risk starts about 10 – 12 %. FAO (2002) presented slope suitability ratings for sprinkler systems for eight groups of crops. Table 5.26 shows the slope suitability ratings for annuals which includes the selected crops in this study (barley, wheat, maize and sorghum).

Table 5. 24 Terrain slope ratings for sprinkler irrigation

Slope gradient classes	0-2 %	2-5 %	5-8%	8-16%	>16%
Barley, Wheat, Maize and Sorghum	S1	S1	S1/S2	S2/N	N

Source: FAO (2002)

The threshold values quoted in many reports and studies in Libya are slightly different from those in FAO (2002). The limits from the FAO based on a general evaluation of sprinkler irrigation, whereas the limits reported in the Libyan studies are based on the common sprinkler systems used in the north west of the country. Therefore, the threshold values in the study area have to be tougher than those in FAO study and based on local experience. Table 5.25 show the threshold values for the slope in the study area.

Table 5. 25 Slope ratings for land suitability classification in the study area

Suitability classes	Highly Suitable S1	Moderately suitable S2	Marginally Suitable S3	Not Suitable NS
Selected crops	0-2 %	>2-4 %	>4-8 %	> 8 %

Source: (developed by the author)

5-6 Discussion

In this chapter a framework for land suitability of the selected crops has been developed. This includes the selection of the land qualities, land characteristics and their threshold values. This was emphasised for all the selected crops. The challenge was to collect the information and reports from the study area. The main source for local information was the library of the Agriculture Research Centre (ARC). A number of studies, reports and data in the ARC produced the main information needed to determine the threshold values. A summary of land qualities, land characteristics and their threshold values for the selected crops are shown in Table 5.26 - 5.29.

Table 5. 26 Suitability rating for land characteristics for Barley

Land Qualities	Land Characteristics	S1	S2	S3	Ns
Temperature Regime	Mean Temperature in the growing season (°C)	15-20	20-30	30-40 10-15	<10 > 40
Rooting Conditions	Rootable Depth (cm)	> 80	80-50	>50-30	< 30
	Soil Texture (classes)	SL, SL CL L, CL, L, CL L,	S CL & S CL L	LS	S
Moisture Availability	Available Water-holding Capacity (mm m^{-1})	> 150	110-150	110-75	< 75
Excess of Salts	Soil Salinity (EC)	0 - 8	> 8 -10	>10-13	>13
	Soil Alkalinity (ESP) (%)	0-15	>15-25	>25-50	> 50
Nutrient Availability	Soil Reaction (pH)	8– 6.5	6.5 – 5.3	5.3 - 5	< 5, > 8
Nutrient Retention	Cation Exchange Capacity (CEC) me/100 g soil	> 16	>8–16	5–8	< 5
	Organic Matter (%)	> 1.5	1.5 - 1	<1- 0.5	< 0.5
Soil Toxicities	$CaCo_3$ in root zones (%)	0- 20	>20- 30	>30-40	>40
Infiltration	Infiltration rate mm h^{-1}	>12	>8-12	6-8	< 6
Oxygen Availability	Soil drainage Class (mm h^{-1})	> 125	>42- 125	17- 42	< 17
Condition for Germination	Gravel and Stones at surfaces (%)	0-3	>3-9	>9-20	> 20
Erosion Hazard	Soil Erosion $ton^{-1}.ha^{-1}$ yr^{-1}	0 - 2	>2 - 5	>5 - 7	> 7
Potential for Mechanisation	Slope Steepness (%)	0 - 2	>2 - 4	>4 - 8	> 8

Source: (compiled by the author)

Table 5. 27 Suitability rating for land characteristics for Wheat

Land Qualities	Land Characteristics	S1	S2	S3	Ns
Temperature Regime	Mean Temperature in the growing season (°C)	15-20	20-25	25-30 10-15	< 10, > 30
Rooting Conditions	Rootable Depth (cm)	>120	120-100	> 100-50	< 30
	Soil Texture (classes)	SL, SL CL L, CL, L, CL L,	S CL & S CL L	LS	S
Moisture Availability	Available Water-holding Capacity (mm m^{-1})	> 150	110-150	110- 75	< 75
Excess of Salts	Soil Salinity (EC)	0 -6	>6 -7.4	>7.4- 9.5	> 9.5
	Soil Alkalinity (ESP) (%)	0-10	>10-25	>25-35	> 35
Nutrient Availability	Soil Reaction (pH)	7.5 – 6.5	6.5 – 5.5	5.5 – 5	< 5 , > 8
Nutrient Retention	Cation Exchange Capacity (CEC) me/100 g soil	> 24	16- >24	8- 16	< 8
	Organic Matter (%)	> 1.5	1.5 -1	<1- 0.5	< 0.5
Soil Toxicities	$CaCo_3$ in root zones (%)	0- 20	>20- 30	>30 -40	>40
Infiltration	Infiltration rate mm h^{-1}	>12	>8-12	6-8	< 6
Oxygen Availability	Soil drainage Class (mm h^{-1})	> 125	>42-125	42 - 17	< 17
Condition for Germination	Gravel and Stones at surfaces (%)	0-3	>3 - 9	>9-20	> 20
Erosion Hazard	Soil Erosion $ton^{-1}.ha^{-1}$ yr^{-1}	0-2	>2 - 5	>5 - 7	> 7
Potential for Mechanisation	Slope Steepness (%)	0 - 2	>2 - 4	>4 - 8	> 8

Source: (compiled by the author)

Table 5. 28 Suitability rating for land characteristics for Maize

Land Qualities	Land Characteristics	S1	S2	S3	Ns
Temperature Regime	Mean Temperature in the growing season (°C)	20-30	18-20	15-18 30- 40	<15, > 40
Rooting Conditions	Rootable Depth (cm)	>120	120-100	> 100-50	< 30
	Soil Texture (classes)	SL, SL CL L, CL, L, CL L,	S CL & S CL L	LS	S
Moisture Availability	Available Water-holding Capacity (mm m^{-1})	> 150	110-150	110- 75	< 75
Excess of Salts	Soil Salinity (EC)	0 -1.7	>1.7 -2.5	>2.5–3.7	> 3.7
	Soil Alkalinity (ESP) (%)	0 - 8	8-15	15-25	> 25
Nutrient Availability	Soil Reaction (pH)	6.0 – 7.0	5.5 – 6.0	5.0 – 5.5	< 5.0 , > 8.0
Nutrient Retention	Cation Exchange Capacity (CEC) me/100 g soil	> 24	>16-24	8-16	< 8
	Organic Matter (%)	> 1.5	1.5 - 1	<1- 0.5	> 0.5
Soil Toxicities	$CaCo_3$ in root zones (%)	0 -15	15 - 20	20 – 35	> 35
Infiltration	Infiltration rate mm h^{-1}	>12	>8-12	6-8	< 6
Oxygen Availability	Soil drainage Class (mm h^{-1})	> 125	>42-125	42 - 17	< 17
Condition for Germination	Gravel and Stones at surfaces (%)	0-3	>3 - 9	>9-20	> 20
Erosion Hazard	Soil Erosion $ton^{-1}.ha^{-1}$ yr^{-1}	0 - 2	>2 - 5	>5 - 7	> 7
Potential for Mechanisation	Slope Steepness (%)	0 - 2	>2 - 4	>4 - 8	> 8

Source: (compiled by the author)

Table 5. 29 Suitability rating for land characteristics for Sorghum

Land Qualities	Land Characteristics	S1	S2	S3	Ns
Temperature Regime	Mean Temperature in the growing season (°C)	24-30	20 - 24	15-20 24-35	< 15, > 35
Rooting Conditions	Rootable Depth (cm)	> 80	80-50	>50-30	< 30
	Soil Texture (classes)	SL, SL CL L, CL, L, CL L,	S CL & S CL L	LS	S
Moisture Availability	Available Water-holding Capacity (mm m^{-1})	> 150	110-150	110- 75	< 75
Excess of Salts	Soil Salinity (EC)	0 – 6.8	>6.8 -8.4	>8.4 -10	> 10
	Soil Alkalinity (ESP) (%)	0-10	10-20	20-30	> 30
Nutrient Availability	Soil Reaction (pH)	>6.0-8.0	>5.5 -6.0	5.0 – 5.5	< 5.0, > 8.5
Nutrient Retention	Cation Exchange Capacity (CEC) me/100 g soil	> 16	> 8–16	5–8	< 5
	Organic Matter (%)	> 1.5	>1-1.5	1- 0.5	> 0.5
Soil Toxicities	$CaCo_3$ in root zones (%)	0 -15	15 -20	20 – 35	> 35
Infiltration	Infiltration rate mm h^{-1}	> 12	> 8	> 6	< 6
Oxygen Availability	Soil drainage Class (mm h^{-1})	> 125	125-42	42 - 17	< 17
Condition for Germination	Gravel and Stones at surfaces (%)	0 - 3	3 - 9	9-20	> 20
Erosion Hazard	Soil Erosion $ton^{-1}.ha^{-1}\ yr^{-1}$	0 - 2	>2 - 5	>5 - 7	> 7
Potential for Mechanisation	Slope Steepness (%)	0 - 2	>2 - 4	>4 - 8	> 8

Source: compiled by the author

5-7 Conclusion

This chapter shows the development of the land suitability framework for each of the selected crops. Land qualities, characteristics and their threshold values were determined. The selection of land qualities and land characteristics has been accomplished by carefully considering the available data, texts, and literature. Three criteria were used to select the land qualities; namely, the effects of land qualities upon use, occurrence of critical values for the land qualities within the study area and the practicability of obtaining information on the land quality.

A spreadsheet was formulated to examine the three criteria. The land quality was selected only if it was very important or moderately important, while less important land quality was omitted from land suitability assessment.

As a result, a set of required land qualities and their associated land characteristics have been selected. These land characteristics are : temperature, rootable depth, soil texture, available water holding capacity (AWHC), soil reaction (pH), soil organic matter (o.m %), cation exchange capacity (CEC), soil salinity (EC), soil alkalinity (ESP), Carbonates ($CaCo_3$), infiltration rate, gravel and stones , soil drainage class, soil erosion and slope steepness. In addition, land characteristics and their threshold values are defined. The basis, upon which the threshold values were selected, was data and information available and trials from the local study area. Additionally, texts, studies and publication from other areas were used as a guide to define that information, which were not available in the study area or Libya.

In the next chapter, a land suitability model is to be constructed to produce a land suitability assessment for the study area. A number of methods and techniques will be examined to identify the suitable one for the study area selected.

6

Land Suitability Model for the Study area

This Chapter presents the development of the land suitability model and explains in detail how different data sources are brought together in a unique way to form the land suitability model and to produce the land suitability classification.

6-1 Introduction

Since the FAO Framework was published (1976), a number of technological developments have facilitated the implementation of its principles. One of the most significant developments has been the advent of using computers and geographic information systems (GIS).

The use of computer in this field has developed rapidly. Computers can assist land evaluation in the storage, retrieval and manipulation of the data and in graphical and statistical representation. A substantial body of literature and research has been dedicated to the application of intelligent systems for land use and management. The aim is to identify the quality of the land, to select appropriate types of cultivation and to plan the management. All these computerised systems are based on a knowledge of land use and management, and use expert systems and/or other intelligent techniques to simulate this knowledge. However, not all systems integrate the same technology and therefore provide different functions to the end user.

GIS facilitates the storage and analysis of a wide range of spatial data. Computerised databases and modelling programmes are now interfaced with GIS in order to facilitate the computational intensive aspects of land evaluation, for example, the stage of matching potential LUT requirements with land qualities.

There is wide range of advanced technology which could be used in land evaluation. However, the key point is that the technological method used has to be justified in terms of efficiency of operation and, above all, its practicality.

It is important to realise that in Libya, information technology and modelling are in their early stages especially in the context of agriculture. It is therefore necessary to select practical tools that can benefit decision-making and agricultural development.

In the following sections a range of automated tools for land evaluation are discussed and an appropriate model is developed for the land suitability in the study area.

6-2 Automated Land Evaluation Tools

6-2-1 Review of Computerised Land Suitability Models

Many methods based on the FAO method involve many repetitive calculations, and are tedious if many alternatives are to be compared. Furthermore, matching tables cannot express all the required interactions between land characteristics. Manual procedures, both for the construction of lookup tables or similar methods and for the calculation of suitability are time-consuming and error prone. Therefore, automated procedures have offered a natural solution (Rossiter, 1996).

One early implementation of the FAO framework was the Land Evaluation Computer System **LECS** system in Indonesia (Wood and Dent, 1983). It offers a simple model in comparison with the complex computer systems that are now being developed elsewhere, but it well illustrates the basic possibilities of computerised evaluation.

Using LECS, a standardised selection of basic physical and economic data relating to each land unit and to the requirements of each utilisation type is stored in the computer and is then analysed in two stages. Firstly, the potential productivity of each land unit is evaluated for each of 22 crops and 10 timber species, each at 3 levels of technology and management input. In parallel, the computer then runs a soil degradation model based on an adaptation of the Universal Soil Loss Equation (USLE), which estimates soil loss under each land use. This result is an indication of the level of conservation measures required.

The second stage assesses potential productivity on an economic basis by predicting the effects of improved management. The conservation model selects options for conservation management and estimates the cost of each. The final output provides individual crop recommendations for each land unit on an economic basis.

LECS uses a simplified procedure to predict local crop yield and land suitability, by assigning the local values of eight land qualities derived from fourteen governing land characteristics. The output from this computer system is an indication of the suitability of each crop on each land unit. In addition, it can provide summaries of land units and the areas within each class and also those areas affected by each crop constraint. By deliberately changing parameters and rerunning the analysis, different results can be attained (FAO, 1985), for instance, one such example would be changing the boundary values assigned to salinity.

In 1988 the first version of the Automated Land Evaluation System (ALES) was released in the United States (Rossiter, 1990). ALES is a computer programme to

evaluate land according to the method presented in the FAO framework for land evaluation, taking into account local conditions and objectives. ALES is intended for use in of regional-scale land evaluation projects. ALES has no fixed list of land use requirements by which land uses are evaluated, and has no list of land characteristics from which land qualities are inferred. ALES was developed by Rossiter and Van Wambeke (1989) and subsequently refined (Rossiter, 1990; Van Wambeke, 1991). ALES offers a structure for a wide range of applications of expert knowledge computerised for quick assessment. ALES has seven components: a framework for a knowledge base; a framework for a database describing the land areas; an inference mechanism; a consultation mode; a report generator and an import and export module (Rossiter and van Wambeke, 1989). ALES is not a GIS and does not itself display maps. However, it can analyse geographic land characteristics if maps units are appropriately defined, and it can directly support the reclassification of IDRISI or ArcInfo maps when the same mapping units as are the same used in the ALES database.
MicroLEIS is a computer-based Land Evaluation Information System, developed for identifying the optimal use of agriculture and forestry land systems under Mediterranean conditions (De la Rosa *et al,* 1992). The MicroLEIS system offers an interactive software suite with comprehensive documentation for planning and researching the sustainable use and management of rural resources, with particular reference to the soils from Mediterranean regions. Its development has been based primarily on information from the Andalusia region, in southern Spain. This system evaluates the land by incorporating the climate, soil and site, land (climate, site and soil) and field (climate, site, soil and management) conditions. The MicroLEIS system comprises of four main modules:

- *Info & Kno-* Information and knowledge database

- *Pro & Eco* -Productivity and Ecosystem Modelling
- *Ero & Con* -Erosion and Contamination Modelling
- *Imp & Res* -Impact and Response Simulation

Since 1990 the MicroLEIS project has been developed by the Land Evaluation Group, Natural Resources Institute and Agrobiology at Sevilla, Spain. This work was the result of the combined efforts of many experts and organisations (De la Rosa, 2000).

LEIGIS is a software application resulting from research by Kalogirou (2002). LEIGIS is designed to support rural planners with the first view of the land suitability for cultivation of certain crops according to the FAO methodology. The aim of this work was to produce a physical evaluation of land capabilities and to use this to provide an economic evaluation of land for different types of agriculture. The implementation of LEIGIS includes models for general cultivation and for specific crops (wheat, barley, maize, seed, cotton, sugar beet) (Kalogirou, 2002). The application provides a physical land evaluation consisting of a model that assigns a score to every land parcel based upon a value given for 16 characteristics. In this system, scores are assigned to individual land characteristics. The latter are combined to form three major groups of characteristics and a total score is then calculated. LEIGIS is based on the hierarchical importance of land qualities. Each land quality is described by one or more land characteristics.

The Intelligent System for Land Evaluation (**ISLE**) is a system that automates the process of land evaluation and graphically illustrates the results on digital maps. This expert system is a land evaluation tool developed in accordance with the FAO methodology for land evaluation. The system has, as an input, a digital map of a study area together with a geographical database. The system displays this map, and evaluates the land units selected by the user and finally visualises the results, colouring properly the analysed land units (Tasoumakas and Vlahavas, 2000). Tables 6.1 and 6.2 show a summary of these expert systems together with their derivation and their benefits and limitations.

Table 6. 1 Comparative analysis of land evaluation expert system

Expert Systems	Place & date	Derivation	Benefits	Limitations
LECS	Indonesia 1983	Land evaluation computer system based upon FAO framework	1- Predicts local crop yield 2 - Suitability of each crop on each land unit	1-Very simple model 2- Developed for a specific area (Sumatra)
ALES	U.S.A 1988	Microcomputer programme allowing the evaluator to build their expert system following the FAO methodology.	1- Offers a structure for a wide range of expert knowledge for a quick assessment 2- Can be linked to socio-economic evaluation 3- Allows the evaluator to build their expert system 4- Has no fixed list for land characteristics of land use requirements	1- It cannot display maps and it has no GIS functions 2- It is not very user friendly
ISLE	Greece 2000	1-It was developed in 1998 in Greece 2-It was designed with specific knowledge 3- Expert system and GIS	1- User-friendly	It does not support a wide range of problems in land evaluation
MicroLEIS	Spain 1992	Computer-based land evaluation information system developed for optimal use of agriculture and forestry land systems under Mediterranean conditions.	1- Predicts appropriate agro-forestry land uses. 2-Interactive software 3- Addresses the land evaluation at reconnaissance semi, and detailed scales 4- Helpful for teaching, research and development	1- It does not allow the evaluator to build their own expert system
LEIGIS	Greece 2001	1- It is based on the FAO framework 2- It has two parts: physical and economic evaluation	1- Does not require advanced computer skills 2- It has simple GIS functions	1- It is limited to five specific crops 2- It does not include some land characteristics such as climate 3- The economic evaluation is very simple and needs further development

Table 6. 2 Feature based comparison of land expert systems

Features	ALES	ISLE	MicroLEIS	LEIGIS
Map Interaction		*	*	*
GIS Linkage	*	*	*	*
Knowledge Base	*	*	*	*
Expert System customisation	*			
User-Friendly Graphical Interface		*	*	

6-2-2 GIS-based Land Suitability Analysis

The GIS-based approaches for land use suitability analysis originate from manual map overlay techniques which were already being developed in the USA in the early twentieth century (Malczewski, 2004). During the 1960s the increasing complexity of land use planning issues provided further impetus for the development of these approaches. In 1964, Christopher Alexander presented an approach in his *Notes on the Synthesis of Form* which did not use overlays but which did involve a specific set of criteria for the location of various activities, and which used matrices aimed at exposing their compatibilities or conflicts. This approach was clear and logical. Thus by the late 1960s map composites were well-established yet were still labour-intensive and error-prone, compared with the analytical solution possible using GIS.

The overlay procedure and principles of multi-criteria analysis that had emerged remain the basis of land suitability analysis today, although a transition from manual to digital methods have since taken place. McHarg (1969) developed many of the early overlay techniques. He proposed procedures that involved mapping data from natural and anthropogenic attributes of the environment . The individual maps were presented as transparencies shaded light to dark (high suitability to low suitability) and were superimposed over each other to construct overall suitability maps for each land use.

The change to digital methods for site suitability analysis was accompanied by several useful studies and papers. A key example of this type of paper is that of Hopkins (1977) in which he constructs the taxonomy for eight general methods available for generating land suitability maps, and presents a comparative evaluation. Hopkins describes and compares eight general methods for generating suitability maps. He shows that each method has both advantages and disadvantages. Hopkins recommended that, for most studies, linear and nonlinear mathematical combinations can be used. This approach entails a rating or scoring of classes of each data layer on a separate interval scale. Multipliers or weightings are then assigned to each layer according to an assessment of its relative importance. The purpose of the weightings is to convert or normalise all ratings to the same interval scale.

In a similar vein, Cornwell (1983) discusses alternative types of numerical scales which may be used when measuring differences in suitability, and demonstrates that these generate differing suitability maps.

GIS is now a very important tool for land use planning. This is due to the capacity of such systems to provide different functions, which benefit land use planning. These capabilities include database management (data integration), cartographic analysis and modelling functions. The ability to integrate data within a GIS is one of the most important features, bringing together data from different sources, formats, and scales and making them compatible with each other (Flowerdew, 1991).

One striking feature of integrated data management is the ability to present different layers of information concurrently, which can help planners and decision makers by showing together varying factors that influences land use (FAO, 1989).

The other unique function provided by GIS is the cartographic analysis of different layers. Once these layers have been integrated in a GIS environment, overlay analysis can be applied easily to produce new layers of information. This facility can improve the overall accuracy and can reduce the time required to undertake these analyses, compared with traditional methods. An example of using this function is the overlay of different layers representing land characteristics to produce a land suitability map for each land utilisation type. Furthermore, these land suitability maps can be overlaid with each other to produce a suitability map showing the best use of each area of land.

The modelling functions provided within a GIS can benefit land use by providing the ability to analyse and model data layers by automatic means. Once the model has been constructed and validated, the repetition of the analysis as assumptions and/or conditions change is a quick and easy task. This function of a GIS can save time and cost in the evaluation of land use options, data management and presentation, when compared with conventional means (Hammer *et al*. 1991).

GIS has the capability to integrate spatial data of relevant environmental factors to allow a land suitability assessment to be made. GIS-based spatial assessment depends on the weighting of relevant factors (or maps in a GIS database) such as soil, climate, erosion, and slope.

6-2-3 Discussion

The FAO framework for land suitability involves the construction of matching tables or the transfer functions and subsequent calculations of suitability. These processes are time-consuming and are liable to errors. Therefore, there are a great number of benefits to be gained in automating the FAO procedures (Rossiter, 1990; Davidson, 1992).

There is no doubt that computer systems and GIS allow land evaluation to be performed more efficiently; they limit the margin for human error, and save time and cost. However, it is certainly correct that the fullest benefit of this technology can only be realised when it is practical and accessible. Automated land suitability for crops in countries where the information technology is in its very early stages, should be made especially user-friendly and accessible for the average computer user. This will prove to be the case in Libya, where, it must be noted that levels of information technology penetration are still relatively low. Therefore, the need for a practical automated land evaluation tool in Libya is apparent and needs to be taken into consideration. The state of the art models will be practically impossible to apply currently, due to the lack of highly skilled information technology personal especially in agriculture sector. This turns the focus to the most practical and efficient method of applying land evaluation in Libya.

The FAO framework for land evaluation is only a set of guidelines and evaluators have to select land characteristics and qualities which differ from one environment to another. Therefore, computer systems used in different environments and different sets of data may not be used for other sets of data and conditions. This applies equally to LECS, MicroLEIS, LEIGIS and ISLE.

ALES is a microcomputer programme which could act as a framework or shell, which can also allow the evaluator to use customised land evaluation.

However, ALES is not very user-friendly and it seems difficult for non-IT expert to make use of it (Kalogirou, 2002).

In addition to a review of computerised land evaluation systems and models, a series of meetings with experts and authorities in to Libya during the period of this study were arranged (see Appendix C for the interview notes). It was certainly clear that in order for computerised land evaluation to be successful, useful, and usable by the authorities, any solution had to be user-friendly so that it could be used by the average computer user. Therefore, the land suitability analysis approach finally selected for this research has been designed to be applied through a spreadsheet model and can be utilised subsequently by those with simple GIS modelling capabilities. In the following sections a detailed description of the model and data process is given.

6-3 Land Suitability Assessment in the Study area

Land suitability evaluation for crop production involves the interpretation of data relating to soils, climate and topography whilst matching the land characteristics with crop requirements. Land qualities and their associated land characteristics were determined in Chapter Five and are arranged in four categories. A match between land use requirements and natural resources is essential to produce a land suitability classification.

6-3-1 Creation of a Land Information System

To facilitate the matching procedure, a database for land resources is needed. The objective is to combine available natural resource data into a suitable format to allow land suitability analysis to take place. The following steps were undertaken to construct a Libya land information system to allow the matching between land use requirements and land resources to take place:

- review and select suitable information technologies;

- compile all sources of data ((soil survey data, soil map, climate data and topographic maps);
- relational database design and normalisation including GIS design;
- prototype construction and classification of thematic map layers.

A number of procedures were followed in compiling the geographic and tabular data input: entering spatial data (digitising); entering the non-spatial; and linking the spatial to the non-spatial data. The data available to this research was discussed in section 4.1.2.

The data available for the research were initially in paper format. All of the soil property data were at soil sub-types level. A soil map was available at a scale of 1:250 000 in a paper format. This was accompanied by a soil report containing the physical and chemical properties of soil was available. The data were provided for each soil taxonomic unit. From this, a database schema was created and populated as part of this research (Figure 6.1).

The soil map contained at least one profile description for each mapping unit. One concern recognised in the research was that there were not substantial numbers of profiles representative of each of the mapping units – however, this had to remain a drawback of the data available for the research. Further to this, it was clear that there was no linked information available concerning the sub-dominance of the soil types within the mapping or associated textual reports. Given the certainty of variations occurring within the map unit, this was also seen as a drawback, again however being representative of the data made available for the research.

The physical and chemical soil characteristics for each of the soil types were provided again within the database, newly created in the research based upon the textual sources.

Further to this, topographic mapping for the study area was also available at a scale of 1:50 000. These paper-based maps were raster scanned and prepared as a GIS data orientation layer.

Finally, climatic data were made available for the Benghazi area. Data were collected from the Benina meteorological station and collated from the paper-based source. Rainfall rates and temperature were available for twenty years. These data, again, were entered within the newly created project database to support the subsequent modelling.

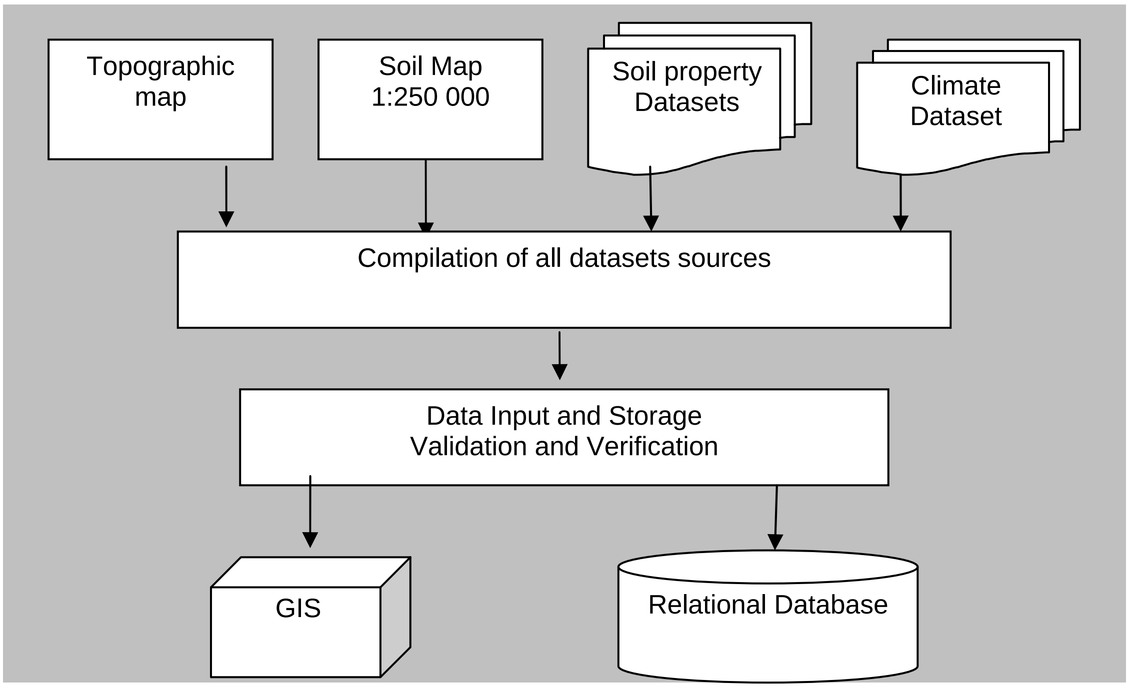


Figure 6. 1 Database scheme for the land evaluation system

6-3-2 Model Construction

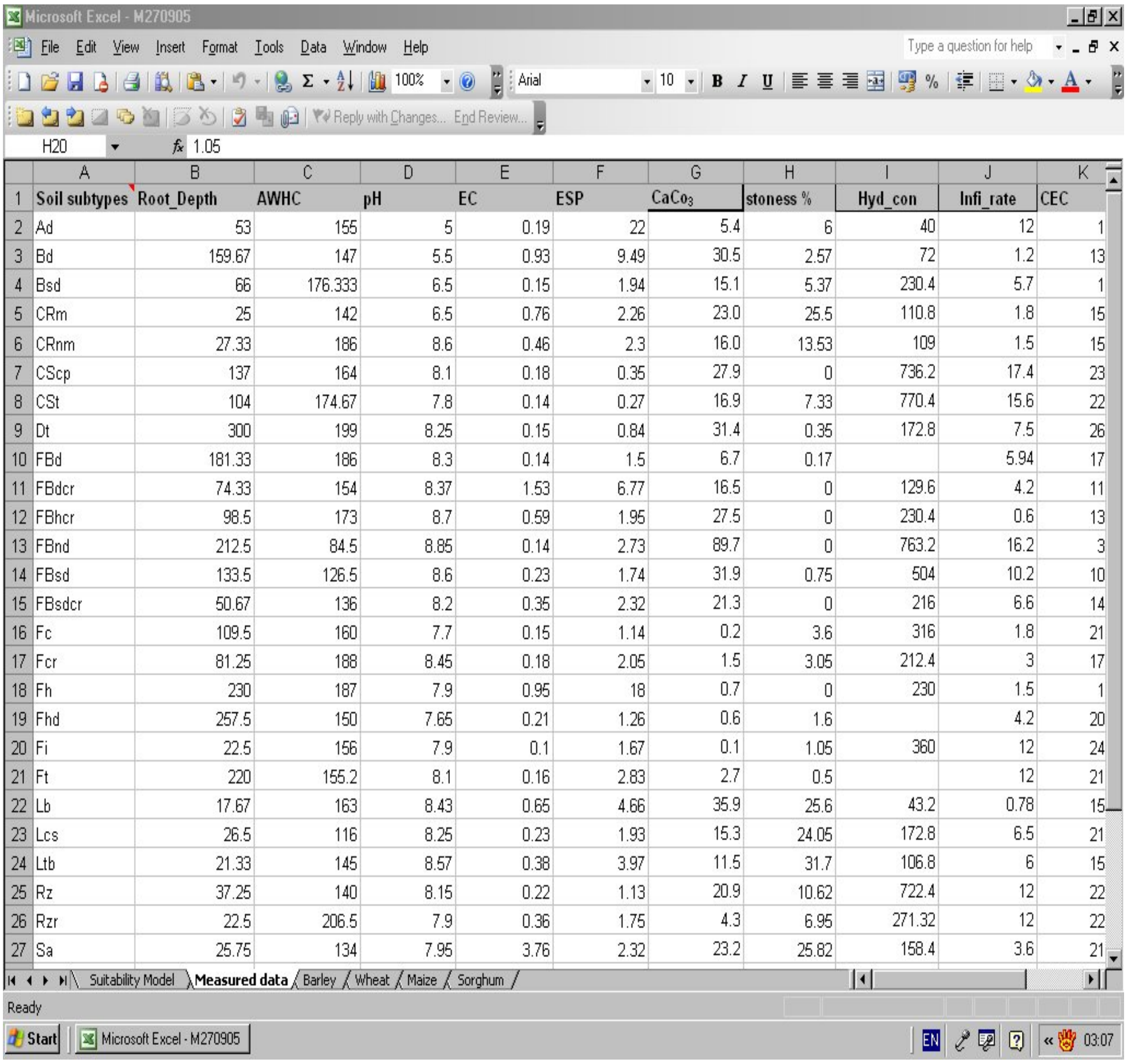
A land suitability model was constructed using GIS capabilities and modelling functions. The ESRI ArcGIS application was selected for this due to its wide prevalence in environmental applications. Model Builder is an ESRI tool that assists in the creation and management of spatial models that are automated and self-documenting. A model is a set of spatial processes, such as overlay, that converts input data into an output map. A spatial model in Model Builder is easy to build, run, save and modify (ESRI, 2000). The GIS Model Builder was used to organise and integrate spatial processes to model the land suitability in the study area.

Soil, climate, erosion hazard and slope are factors which are important for land suitability for the selected crops in the study area. Those factors were integrated into the GIS environment as information layers and then overlaid to produce overall land suitability assessment for each land utilisation types (Figure 6.2 to Figure 6.6).

The suitability analysis for soil and climate was calculated in a spreadsheet model (see Figure Appendix D). A GIS allows the results to be displayed graphically, but this does not make full use of the analytical capabilities of the GIS. In order to use the full GIS analytical capabilities the soil observations and the relevant datasets have to be in geo-referenced form. This provides the opportunity to investigate the relationships between datasets in a unique way. Soil observations and datasets were not available in geo-referenced form in the study area.

Layers were produced from the suitability analysis results and integrated within the GIS. The other two layers are the erosion layer and the slope layer. All four layers were held in raster format. The erosion and slope layers were reclassified to produce suitability input layers. Using the threshold values discussed in Chapter Five, soil losses were split into five classes. The slope layer was reclassified to produce a new theme.

In the following sections the process of producing each thematic layer is presented graphically and explained. A series of screen-images from the model developed indicate the sequence of the user-interface design.



	Soil subtypes	Root_Depth	AWHC	pH	EC	ESP	$CaCo_3$	stoness %	Hyd_con	Infi_rate	CEC
2	Ad	53	155	5	0.19	22	5.4	6	40	12	1
3	Bd	159.67	147	5.5	0.93	9.49	30.5	2.57	72	1.2	13
4	Bsd	66	176.333	6.5	0.15	1.94	15.1	5.37	230.4	5.7	1
5	CRm	25	142	6.5	0.76	2.26	23.0	25.5	110.8	1.8	15
6	CRnm	27.33	186	8.6	0.46	2.3	16.0	13.53	109	1.5	15
7	CScp	137	164	8.1	0.18	0.35	27.9	0	736.2	17.4	23
8	CSt	104	174.67	7.8	0.14	0.27	16.9	7.33	770.4	15.6	22
9	Dt	300	199	8.25	0.15	0.84	31.4	0.35	172.8	7.5	26
10	FBd	181.33	186	8.3	0.14	1.5	6.7	0.17		5.94	17
11	FBdcr	74.33	154	8.37	1.53	6.77	16.5	0	129.6	4.2	11
12	FBhcr	98.5	173	8.7	0.59	1.95	27.5	0	230.4	0.6	13
13	FBnd	212.5	84.5	8.85	0.14	2.73	89.7	0	763.2	16.2	3
14	FBsd	133.5	126.5	8.6	0.23	1.74	31.9	0.75	504	10.2	10
15	FBsdcr	50.67	136	8.2	0.35	2.32	21.3	0	216	6.6	14
16	Fc	109.5	160	7.7	0.15	1.14	0.2	3.6	316	1.8	21
17	Fcr	81.25	188	8.45	0.18	2.05	1.5	3.05	212.4	3	17
18	Fh	230	187	7.9	0.95	18	0.7	0	230	1.5	1
19	Fhd	257.5	150	7.65	0.21	1.26	0.6	1.6		4.2	20
20	Fi	22.5	156	7.9	0.1	1.67	0.1	1.05	360	12	24
21	Ft	220	155.2	8.1	0.16	2.83	2.7	0.5		12	21
22	Lb	17.67	163	8.43	0.65	4.66	35.9	25.6	43.2	0.78	15
23	Lcs	26.5	116	8.25	0.23	1.93	15.3	24.05	172.8	6.5	21
24	Ltb	21.33	145	8.57	0.38	3.97	11.5	31.7	106.8	6	15
25	Rz	37.25	140	8.15	0.22	1.13	20.9	10.62	722.4	12	22
26	Rzr	22.5	206.5	7.9	0.36	1.75	4.3	6.95	271.32	12	22
27	Sa	25.75	134	7.95	3.76	2.32	23.2	25.82	158.4	3.6	21

Figure 6. 2 Database for Soil Sub types

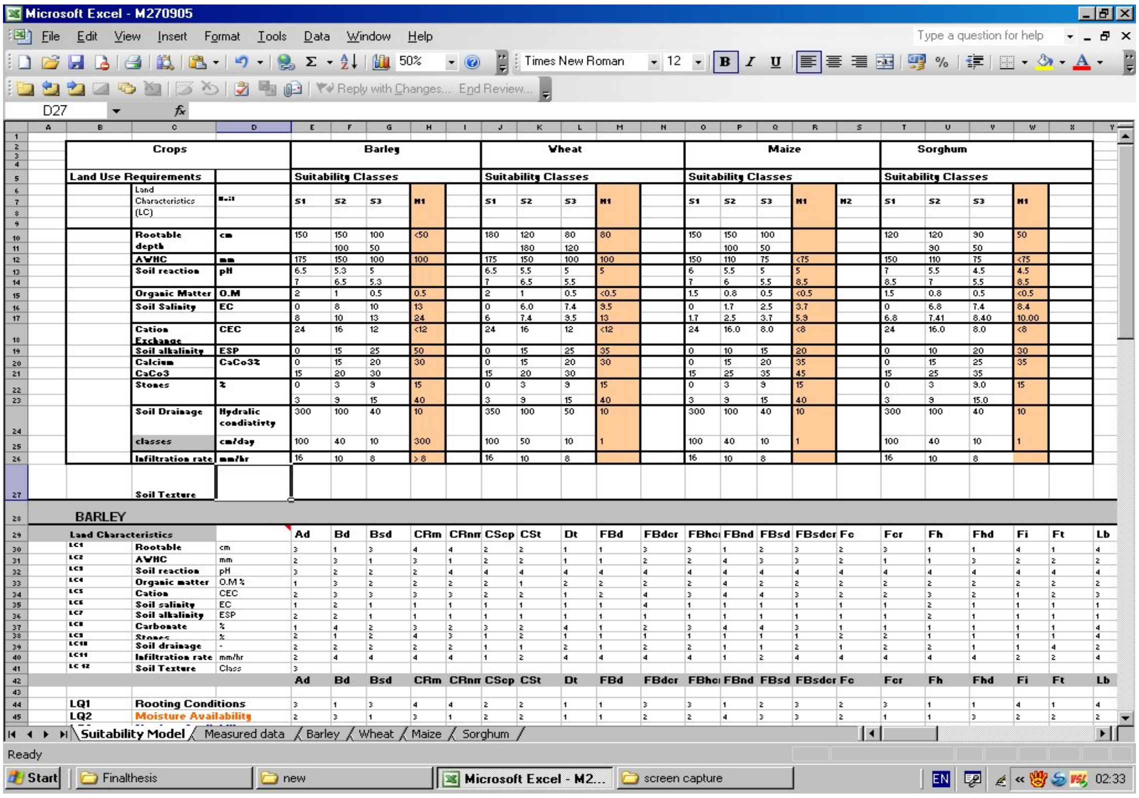
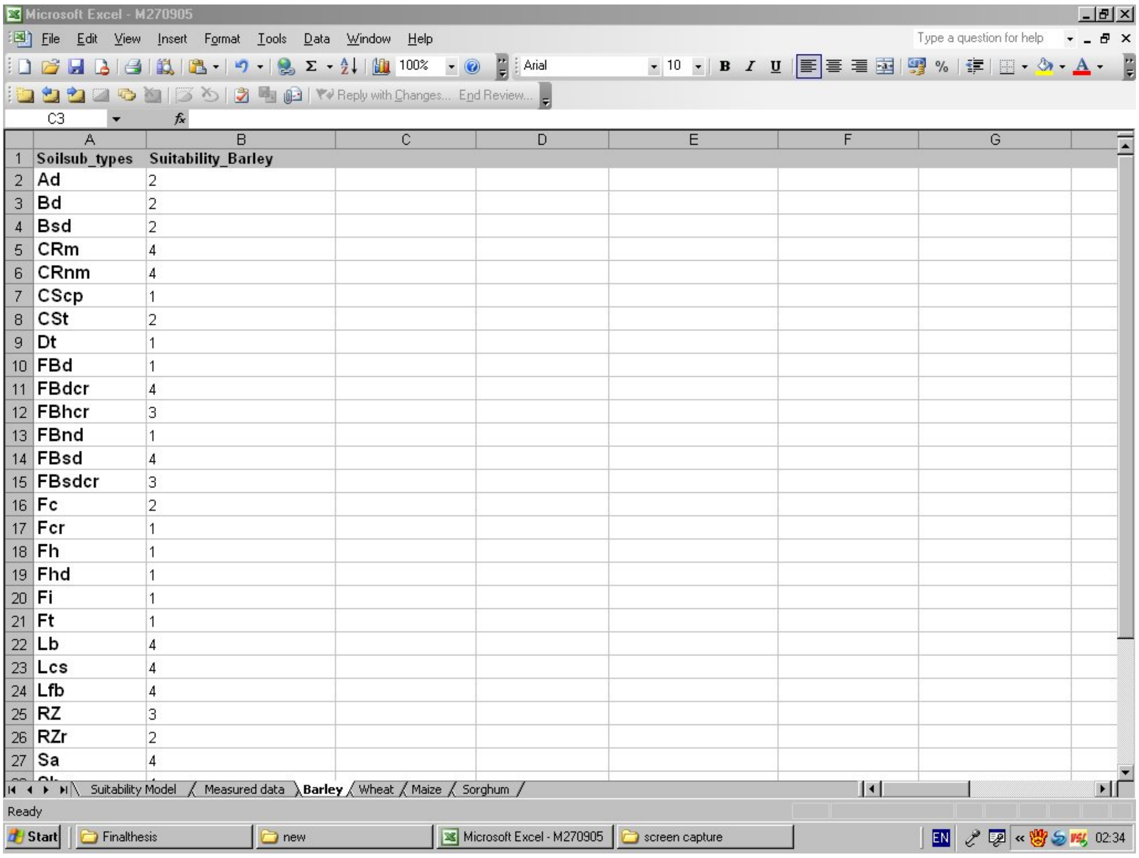


Figure 6. 3 Spreadsheet Model for land suitability assessment



Soilsub_types	Suitability_Barley
Ad	2
Bd	2
Bsd	2
CRm	4
CRnm	4
CScp	1
CSt	2
Dt	1
FBd	1
FBdcr	4
FBhcr	3
FBnd	1
FBsd	4
FBsdcr	3
Fc	2
Fcr	1
Fh	1
Fhd	1
Fi	1
Ft	1
Lb	4
Lcs	4
Lfb	4
RZ	3
RZr	2
Sa	4

Figure 6. 4 Soil suitability classes in the spreadsheet model

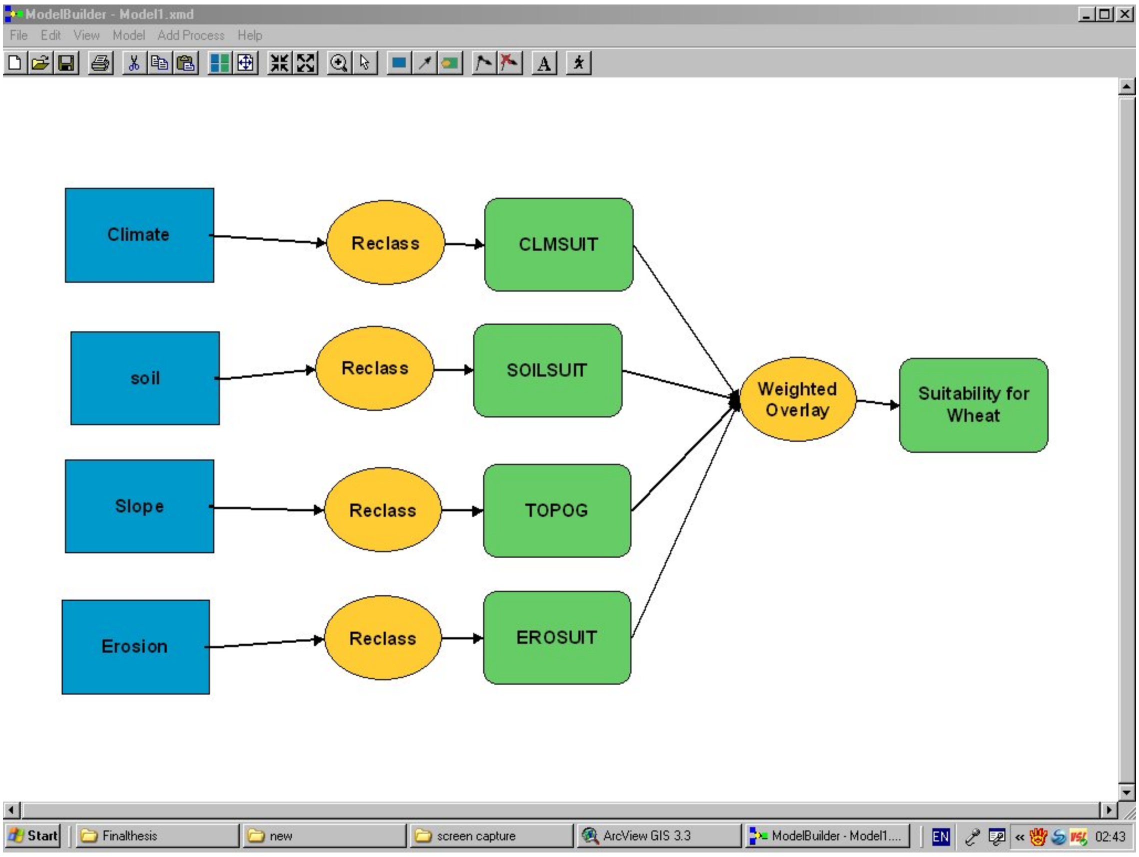


Figure 6. 5 Land suitability model and the overlay of thematic maps to produce overall land suitability map

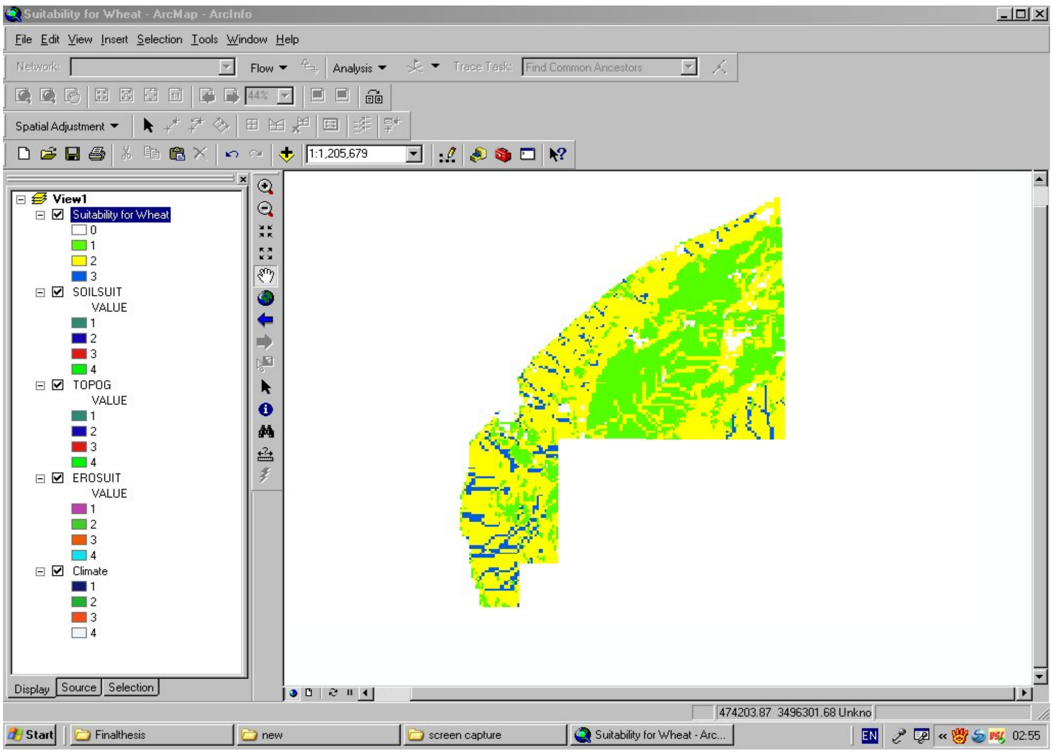


Figure 6. 6 Land suitability model in Arc GIS

6-3-2-1 Climate Thematic Layer

A spreadsheet was compiled to assess the suitability classes based upon temperature. The threshold values for the suitability classes were identified in Chapter Five. From the climate database, temperature data was derived within the spreadsheet model. The suitability classes are exported to the database and then the climatic layer was created in ArcGIS.

6-3-2-2 Soil Thematic Layer

Land qualities related to soil were grouped in the spreadsheet model used to carry out the suitability analysis. The land characteristics were classified according to the threshold values. The data were then exported from the database to the spreadsheet model.

In the spreadsheet model, the Boolean "if" function was used to set the suitability class limits between land suitability classes for each land characteristic. The overall land suitability class for each crop was determined and exported from the spreadsheet model to the database. By using the GIS, a layer of soil suitability was subsequently produced. Figures 6.7 demonstrates the data processing method.

This layer was one of the four layers forming land suitability model. These four layers were overlaid to produce the final land suitability for each crop.

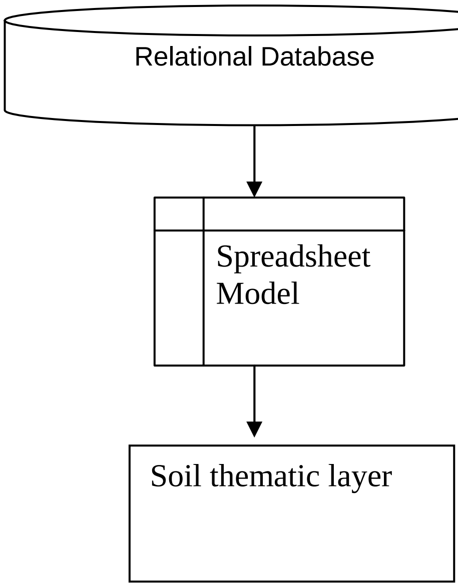


Figure 6. 7 The process of producing the soil thematic layer in the land suitability model

6-3-2-3 Erosion Thematic layer

The Universal Soil Loss Equation (USLE) was applied in the GIS to determine the average annual soil loss in the study area. The USLE is designed for predicting soil loss at a field scale, as a basis for the selection of conservation practices for specific sites, but it is not intended for predicting soil loss from a watershed or other larger areas. It can, however, be used for the latter purposes by subdividing the area under consideration into sites with similar characteristics, and by calculating the soil loss for each of these, and multiplying by their relative extent proportionately.

The USLE predicts soil loss for a given site as the product of six major factors (Equation 6.1) whose value in a particular location can be expressed numerically (Wischmeier and Smith, 1978).

The values of the equation vary considerably about their means but the effect of these fluctuations averages over time. Thus the USLE is suitable for predicting long-term averages; the soil erosion is calculated as follows:

$A = R \times K \times L \times S \times C \times P$ **Equation 6. 1**

A = Annual soil loss in $t\ ha^{-1}\ y^{-1}$

R = Rainfall erosivity factor ($J\ mm.m^{-2}\ h^{-1}$)

K = Soil erodibility factor ($t\ J^{-1}\ mm^{-1}$)

L = Slope length factor

S = Slope steepness factor

C = Crop and management factor

P = Conservation-supporting practices factor

The data for the model were obtained from Benina weather station, soil survey data and topographic maps. Individual GIS files were built for each factor of the USLE and combined by utilising the grid-cell modelling function in ArcGIS (ESRI, 2000) to predict soil loss in the spatial domain.

- **Determining Rainfall erosivity (R)**

Rainfall erosivity constitutes an important factor for the understanding of the geomorphological processes that are taking place in a territory. However, this parameter is often difficult to estimate, due to the lack of the necessary pluviometric records. Therefore, some other equations such as the Fournier index can estimate, with good accuracy, monthly and/or annual values of rainfall erosivity by using pluviometric records, such as annual and monthly rainfall averages. The Fournier index presented in (Equation 6.2) represents an equation widely used for this purpose:

$Cc = M^2x / P$ **Equation 6. 2**

Cc = Fournier index

M = Monthly value of precipitation (mm) for month x

P = The annual values of precipitation (mm)

Rainfall erosivity was determined using data from the Benina meteorological station in t Benghazi, for which monthly and annual values of precipitation records were available.

- **Determining Soil Erodibility (K)**

The aim of the soil erodibility assessment is to provide a factor K which is spatially interpolated for the whole study area, for the calculation of soil loss within the USLE. Figure 6.4 shows a flow diagram of the steps taken in determining the K-factor of the soil in the study area.

The relation between erodibility and the physical and chemical properties of some Libyan soils are studied by (El-Asswad and Abufaied, 1994). Fifteen equations were produced expressing the relation between soil physical and chemical properties (Clay%, Sand%, Silt%, EC, pH, $CaCo_3$ %, organic matter, bulk density and permeability). The findings of the study were in agreement with findings by Wischmeier and Smith, (1971; 1978). Figure 6.7 shows a map of the K-factor values present in the study area. The K – factor was calculated for each soil sub-type. The map in Figure 6.7 shows a classification for k- factor to give an indication about the k- factor distribution. The K-factor has been grouped together into classes to give a general overview. A more detailed map could be created for smaller areas showing the individual K-factor for each soil sub-types.

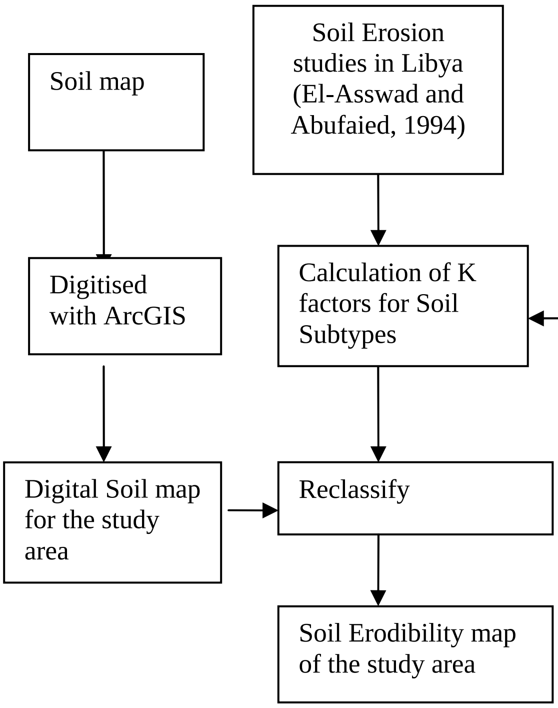


Figure 6. 8 Determination of the erodibility K-factor of the soil in the study area

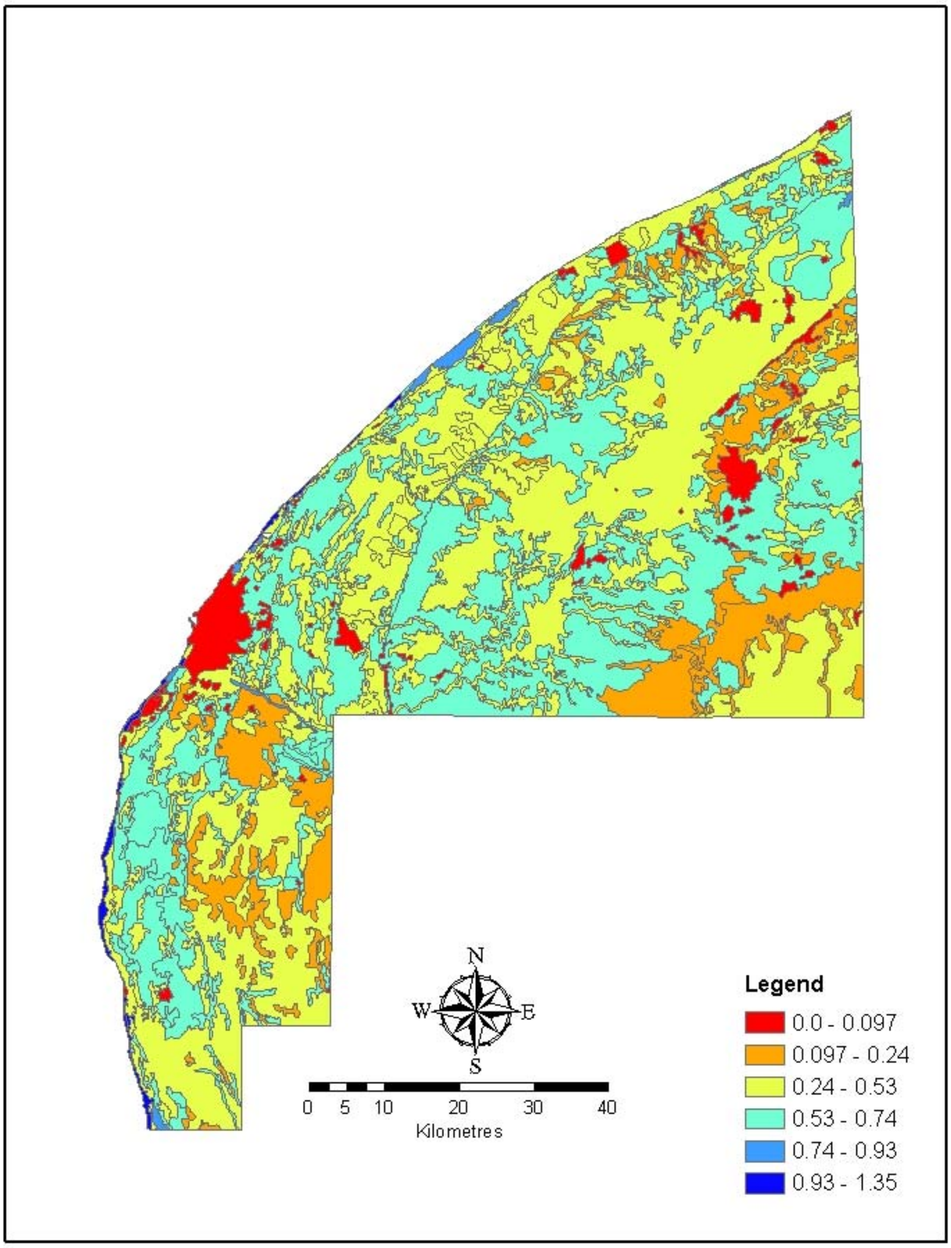


Figure 6. 9 Soil Erodibility in the study area

- **Determining Crop and management factor (C) and Conversation factor (P)**

The factors C and P are derived from the specification of land utilisation type (for each of the selected crops). For each crop, there is a land use factor and value which is used in the estimation of soil loss.

Compared to the other factors of USLE, research on the P factor has been rather limited. Thus, P-factors have been taken from the original values developed in the USA by Wischmeier and Smith (1978). The values of P range from about 0.05 for reverse-slope bench terraces, to 1.0 where there are no erosion control practices (Wischmeier and Smith, 1978).

- **Determining the topographic factors (LS)**

The factors of slope steepness (S) and length (L) can be calculated separately or they can be merged into a single index (LS), which expresses the ratio of soil loss under the steepness and length of slope, to the soil loss from the standard USLE plot conditions, The L and S factor can be obtained from the equations developed by Wischmeier and Smith (1977) (equation 6.3 and 6.4).

$S = 65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065$ **Equation 6. 3**

$L = (\lambda / 22.13)^m$ **Equation 6. 4**

θ = angle of the slope

λ = Slope length in m

m = an exponent that depends on slope steepness and m is 0.5 for slope steepness exceeding 5 per cent slopes, 0.4 for 4 per cent slopes and 0.3 for slopes less than 3 percent.

Equations 6.3 and 6.4 were developed for single uniform slopes. The topographic factor (LS) described will usually overestimate soil loss from concave slopes, and underestimate loss from convex slopes. To correct for irregular slopes, Foster and Wischmeier (1974) proposed the following adaption to the USLE equation:

$A = RKCP\,[\sum (S_j X_j^{1.5} - S_j X_{j-1}^{1.5}) / X_e (22.13)^m]$ **Equation 6. 5**

Where,

X_j = distance from the top of the slope to the lower end of the segment (m)

X_{j-1} = slope length from the top of the hill to the upper end of the segment (m)

X_e = Overall slope length (m)

S_j = the value of the slope–gradient factor for the j segment and A, R, K, C, P and m= are as defined previously (in equation 6.4).

For long slopes on which rill and interill erosion occurs, the LS factor has been found to consist of two linear relationships with break points at the 9 percent and 1 percent slope (McCool *et al*, 1977). These relationships predict less erosion on slopes steeper than 9 percent and also on slopes flatter than 1 percent compared to the original Wischmeier's equation. The two equations are given as follows:

$S = 10.\ \text{Sin}\ \theta + 0.03$ for slopes < 9 % **Equation 6. 6**

$S = 10.\ \text{Sin}\ \theta - 0.50$ for slopes > 9 % **Equation 6. 7**

These relationships describe the increase in soil erosion as the slope steepness increases due to the formation of larger rills on the steep slope.

The application of the USLE in a GIS environment has greatly benefited from the possibilities of generating digital elevation models (DEM) using contour maps (Burrough, 1976). Thus algorithms for automatically determining the USLE LS- factor in the GIS have been developed (Desmet and Govers, 1996). In a simplified form, Moore *et al* (1991) developed the equation 6.8, for the LS factor in GIS:

$$LS = (m+1) \times (A_s / 22.13)^{m} \times (\sin \theta / 0.796)^{n}$$ **Equation 6. 8**

n = 1.3

A_s = the specific catchment area, while *m* and θ are defined previously.

This equation was derived from the unit power theory proposed by Moore and Burch (1976), and is better to suited to landscapes with complex topographies than the original given by Wischmeier and Smith (1978), as it explicitly accounts for flow convergence and divergence through the A_s term in the equation. In applying the USLE for large catchments, the LS factor determination is very important. The Moore *et al* equation (1991) was used, as a very high resolution input DEMs was available.

Digital topographic data for the study area were obtained from 50 sheets of topographic maps at scale of 1:50 000 digitised by the Survey of Libya. This work was done with PC ArcInfo (ESRI, 2000).

- **Creation of a DEM**

The Digital Elevation Model (DEM) of the study area was generated using TOPOGRIDTOOL within Arc/Info (ESRI, 1997). The TOPOGRIDTOOL generates a hydrologically-correct grid of elevation data points from stream and elevation coverage. A grid cell size of 10 m was used (Figure 6.10).

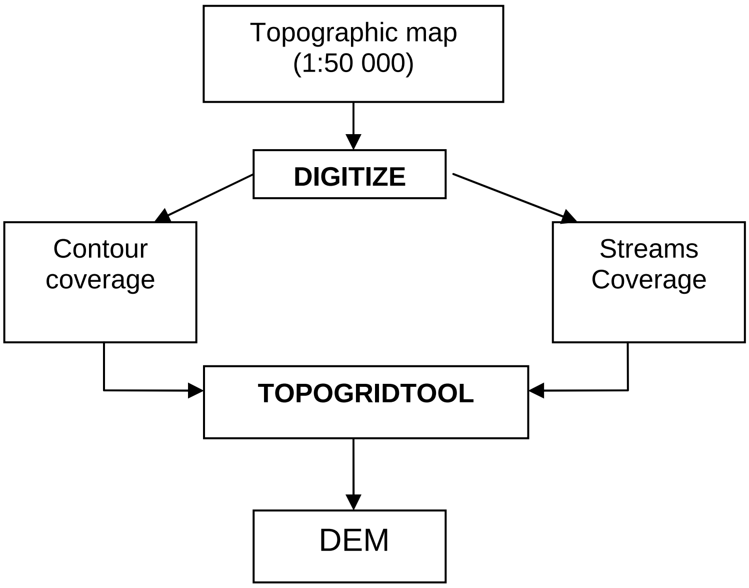


Figure 6. 10 Procedures in the preparation of DEM and LS-factor maps

- **Determining erosion land quality**

The calculation of soil loss for the erosion hazard map was done directly in ArcGIS, by multiplying the respective USLE grid files (Figure 6.11). The resulting output grid files contained actual calculated values of soil loss for each crop.

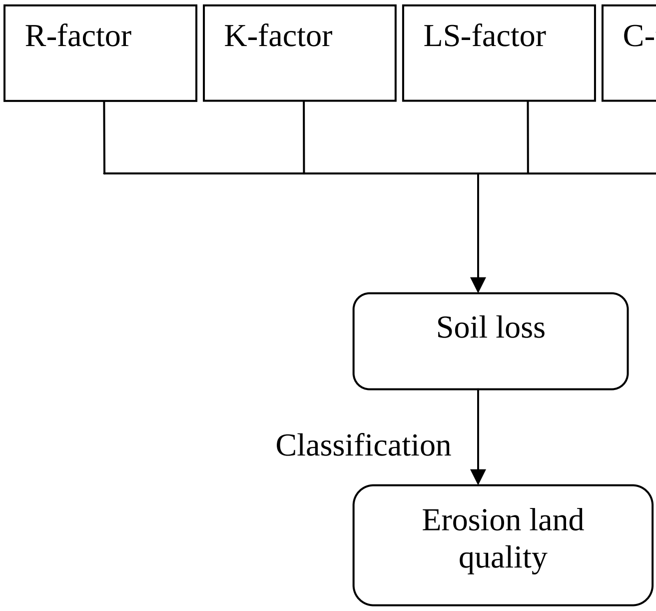


Figure 6. 11 Application of the USLE to determine erosion hazard

- **Discussion**

The amount of erosion was estimated using the USLE (Equation 6.1). The source data were limited to rainfall studies and the soil map displaying only the representative values of the soil variables. The only available source of climatic data was the Benina meteorological station. Moreover, the R, L, and S factors were themselves derived through the use of several regression formulae. The equation therefore incorporates a series of discrete data sources, each of which has in itself a degree of uncertainty. In combining these data sources together, there is a concern that one is compounding the uncertainty, magnifying it in the result. The ambition is therefore to minimise as far as possible uncertainties in each constituent data source, whilst recognising the difficulties of limited, missing and incomplete input datasets. Examples exist in the literature (Burroughs, P, 1992) as to how this approach can be recognised. In this research, the datasets available in the Libyan context effectively preclude such bracketing of uncertainty due to the limited nature of the source information available.

6-3-2-4 Topography Thematic layer

Topography is expressed in slope percent and is derived from the topographic maps. A layer containing the slope grid for the study area was prepared from DEM using surface function of ArcGIS.

6-4 Conclusion

A land suitability framework for the study area based on the FAO framework was developed in Chapter Five. A number of land qualities and land characteristics were selected and were placed in to four groupings, namely; climate, soil, erosion hazard and topography.

Matching land use requirements with land natural resources is an essential part of land suitability classification. The manual matching procedures involve many repetitive calculations. This approach can therefore take a time if a large number of alternatives are to be compared. Furthermore, manual suitability assessments are time-consuming and are likely to produce errors. Therefore, the application of an automated method of land evaluation comes as a natural development. Computers have been applied to land evaluation at many different levels. One of the most significant developments has been the integration of GIS within the land evaluation process.

A land suitability model was developed using weighed overlay method in the GIS to produce a land suitability classification in the study area. Four layers (soil, climate, erosion hazard and topography) were integrated within a GIS environment and overlain to produce The final step in the process is to allow these weightings to be varied, both to investigate model sensitivity, and also to allow the deviation of the final model configuration. In the next chapter the final land suitability results are presented and assessed, together with sensitivity analysis carried out on the land characteristics.

7

Results and Discussion

This Chapter presents the results and discussion. The land suitability classification results are explained and the sensitivity analysis is evaluated.

7-1 Model Outputs

The weighted overlay technique was used to produce the land suitability for each crop (Figure 6.2). This approach is a technique for applying a common scale of values to diverse and dissimilar input in order to create an integrated analysis. The weighted overlay process allows for the consideration of geographic problems which may often require the analysis of different factors such is the case with land suitability analysis. These factors may not be equally important. The weighted overlay approach allows different weights to be applied to different thematic layers.

During the first run of the model, equal weighting were applied to each layer (soil, climate, erosion, and slope). The results are shown in Table (7.1) with the area covered by each land suitability class shown as a percentage. The output data is a raster (grid) file containing the suitability classes. Each cell in a grid stores a number which indicates the suitability class for that cell.

This study revealed that the study area has a good potential to produce the selected crops under irrigation provided that the water requirement are met.

Nearly 47 % of the study area is highly suitable for barley and 34 % of the study area is suitable for wheat production. In addition, 48 % of the study area is highly suitable for maize production and 70 % of is highly suitable for sorghum production. However, further economic evaluation is needed to identify the economic potential of each crop.

Table 7. 1 Percentage land suitability classes for selected crops, equal land quality weighted

Crop	Suitability Classes in the study area %				
	Highly Suitable S1 %	Moderately Suitable S2 %	Marginally Suitable S3%	Not Suitable NS %	No Data
Barley	46.5	44	4.2	-	5.3
Wheat	34.3	55.1	5.3	-	5.3
Maize	48.2	41.4	5.1	-	5.3
Sorghum	70.9	23	0.8	-	5.3

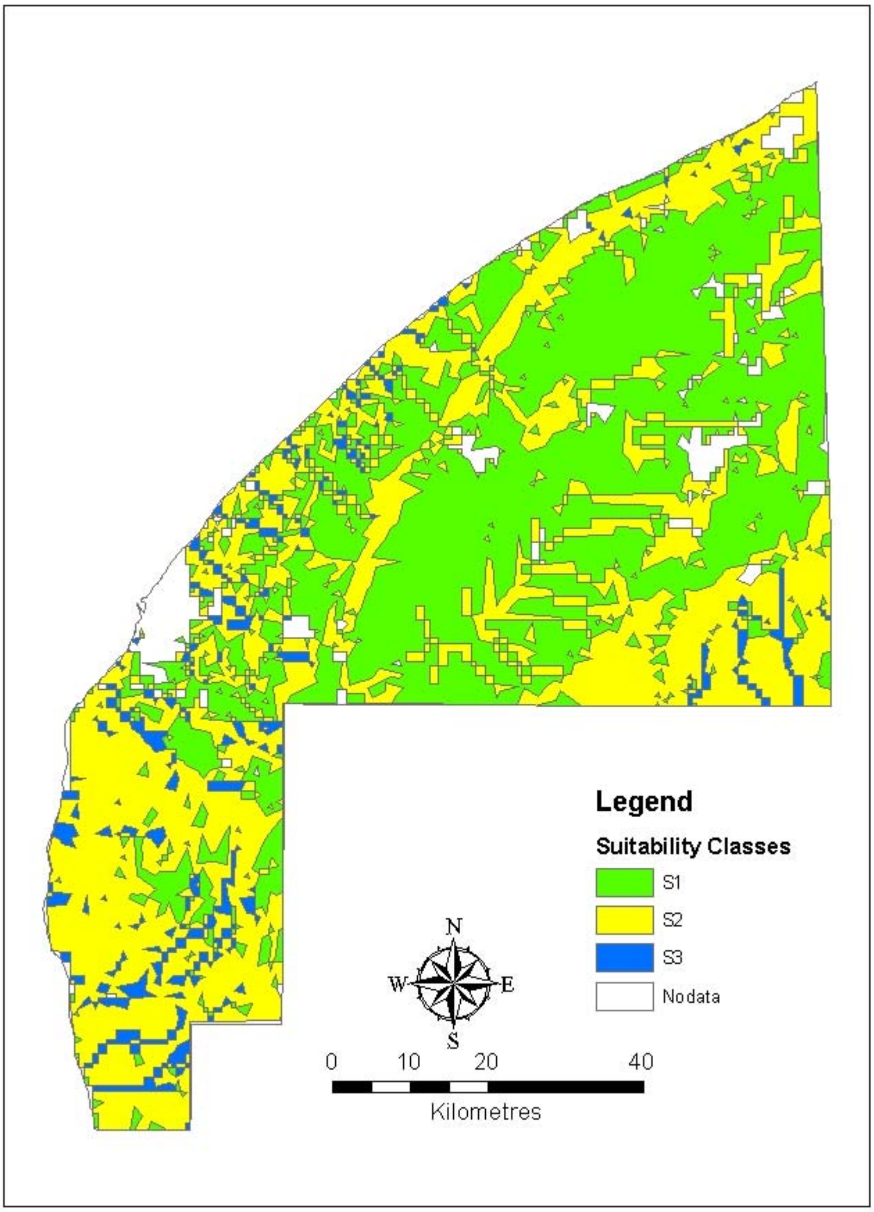


Figure 7. 1 Land suitability map for Barley in the study area

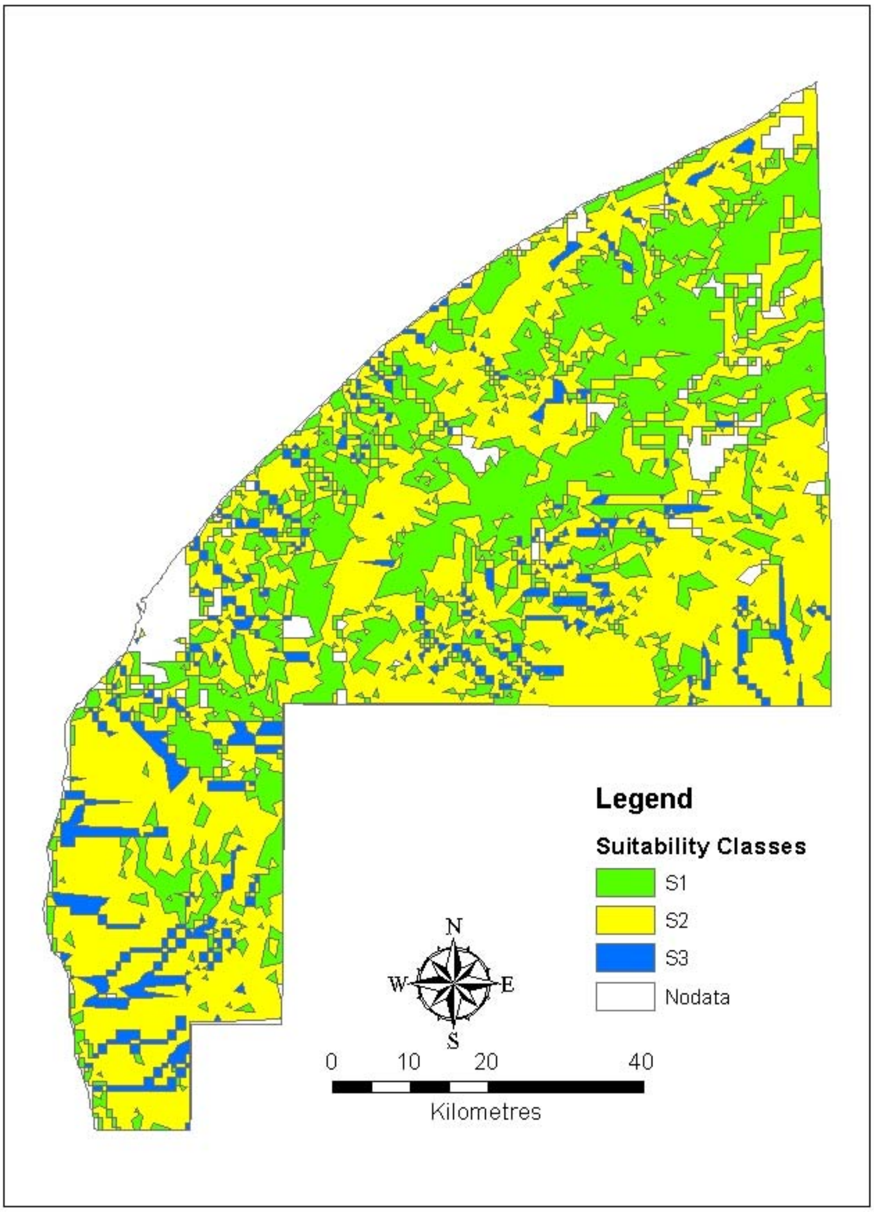


Figure 7. 2 Land suitability map for Wheat in the study area

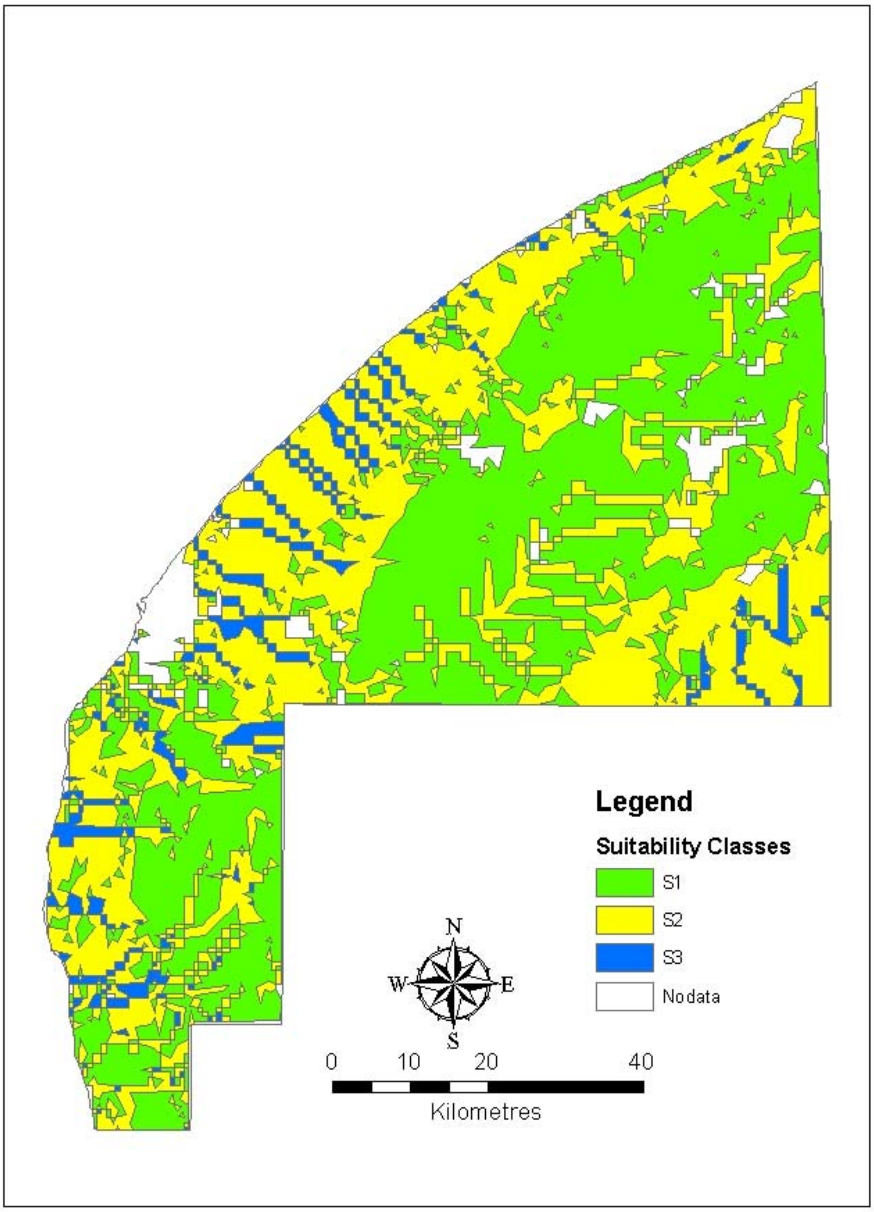


Figure 7. 3 Land suitability classes for Maize in the study area

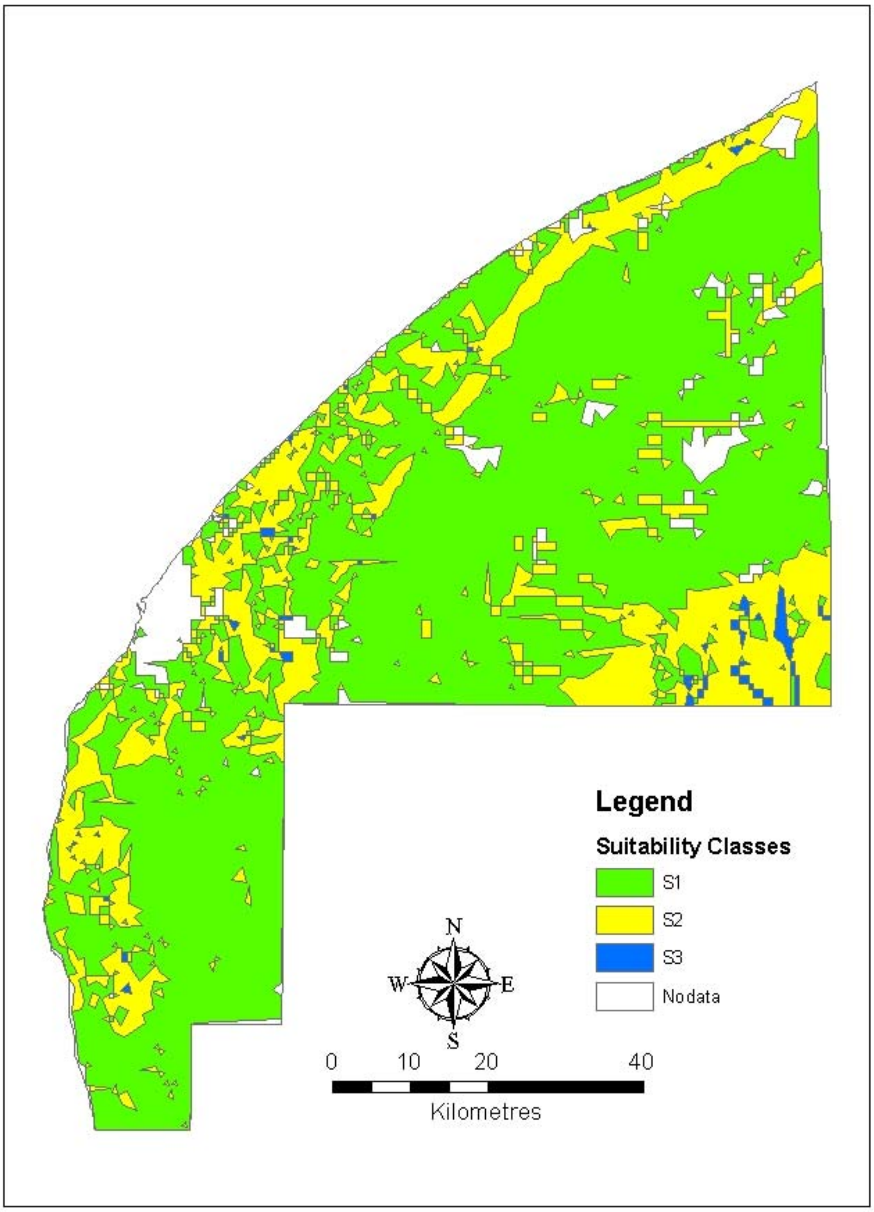


Figure 7. 4 Land suitability classes for Sorghum in the study area

7-2 Model Evaluation

The capability of GIS to perform an integrated analysis of spatial and attribute data has been used in this research to conduct a suitability analysis, and to produce maps from multi-source datasets (climate, soil, topography). Data input used in execution of any model is usually subject to diverse sources of uncertainty (measurement errors in data acquisition, format conversions, lack of information, etc.) that could have considerable influence on the output. It is necessary, therefore, to perform a certain amount of testing to gain confidence in any model, as well as demonstrate that the model is a reliable representation of a real system. Qureshi *et al*. (1999) states that a model evaluation may be divided into three components: verification, validation, and sensitivity analysis. Verification refers to ensuring that model properly implements its specifications. Validation is to ensure that the structure of the model is correctly built from a conceptual and operational point view (if it is appropriate for it intended purpose). Sensitivity analysis examines the stability of the model, checking the extent of variation in the output when parameters are systematically varied over a given ranges of interest, either individually or combined (Delgado and Sendra, 2004). In the following sections, the sensitivity analysis for the model as undertaken is explained in detail.

7-2-1 Model Validations

It is widely accepted that the validation and accuracy of physical land evaluation that uses a qualitative method is not possible (FAO, 1984; Rossiter, 1995). One of the methods that could be used for validation is investigating if the selected crops already produced in the region and then a subjective comparison could be made. If the conditions existing in a region reflect the results in a logical and acceptable manner, the findings become more viable.

It is very important to establish further trial plots on widely distributed soil types across the region where the soils are properly defined. Specific crop rotation trials need to be established for efficient land use planning whereby in land evaluation models crop rotations rather than single crops could be defined for each LUT. For the quantification of the results, local farmers' yields could be used. However, this was not possible in this study for two reasons: firstly, the current land use in the study area is mainly rainfed agriculture and secondly, there are social difficulties. These social difficulties can be divided in two: first, most of the farmers who own irrigated farms are not educated and do not keep a detailed records of their crop yields; secondly, the farmers' misconception of the research. This misconception relates predominately to the intended use of the information i.e. they are concerned that information gathered may be used to impose additional taxation. Therefore, qualitative data (rather than quantitative) regarding the yields obtained in the study area, gathered during previous study by this author and verified during this study will be used to validate the results. Local knowledge indicates that the Al Marj region and Kathrea near Benghazi area are the best areas to produce barley and wheat. The soils in the Al Marj area are mainly Rendzinas. The soils in the Kathra area are mainly Reddish brown arid soils. The outputs of the model indicated that both areas are ranked in the highly suitable classes for both barley and wheat.

The local experts' judgement and knowledge were consulted to validate the results of the model. The model outputs for the selected crops were viewed by the local experts. The expert's opinions, which based on experience in the local context, revealed that the results of the model are in agreement with what is expected of the land in the study area. This was vitally important since the ratings of different land qualities are mainly based on experience and judgement in the project area. This is considered a quality control measure for the land evaluation process a whole.

7-2-2 Sensitivity Analysis

Sensitivity analysis is required the development of models in any scientific field. A model is a simplified version of a part of reality that offers a comprehensible description of a problem situation (Qureshi *et al*, 1999).

Sensitivity analysis examines the extent of variation in predicted performance when parameters are systematically varied across a range of interest, either individually or in combination. Sensitivity analysis provides further confidence in a model, and indicates priority areas for refinement if further versions of a model are to be developed.

Many techniques for sensitivity analysis have been proposed, for example, linear regression or correlation analysis, measure of importance, sensitivity indices, etc. A thorough description of such techniques can be found in Saltelli *et al.* (2000). The usual sensitivity analysis in land suitability GIS-based models is to answer questions such as:

- If the weights change, will the final ranks vary?
- How would the optimum land suitability change as the main model parameters change?
- What are the limits of variation of the parameters so as to leave the overall suitability outputs unaffected?
- Is there a parameter set that does not vary the final results?

By this, the sensitivity analysis offers interesting possibilities to determine what the most important parameters in given models are. In this research, the sensitivity analysis was conducted at two levels. Firstly, sensitivity analysis was conducted on the suitability criteria. Secondly, sensitivity analysis was conducted on the land characteristics within each land quality.

7-2-3 Sensitivity Analysis for Suitability Criteria

The general purpose of sensitivity analysis for the suitability criteria was to find out the influence of different criteria weights on the spatial pattern of the suitability classification. This is useful in situations such as where uncertainties exist in the definition of the importance of different suitability criteria. It is also important to observe how the results will change if the weights are changed.

In practise, sensitivity analysis was accomplished by applying different weighting schemes for the suitability criteria. In the basic computation, an equal weight of 25 % was given to the four criteria (climate, soil, slope, and erosion). In addition to this basic calculation, twenty three weighting schemes were constructed and run using the model's implementation in Arc GIS. The weighting schemes were applied for all the crops (barley, wheat, maize, and sorghum). Table 7.2 shows the weighting schemes (models).

For the purpose of sensitivity analysis, suitability maps for every weighting scheme were created in the GIS. The outputs (suitability maps) were compared to investigate the influence of each criterion on the overall suitability for each crop. Visual assessment of the suitability classes and percentage area calculation of suitability classes were conducted to interpret the output of the sensitivity analysis. By comparing the percentage area of the suitability classes for the different weighting scheme, the sensitivity of the suitability criteria can be assessed. The full outputs of sensitivity analysis are shown in Appendix (E). In the following sections, the results of sensitivity analysis for each crop will be presented.

Table 7.2 overleaf shows the weighting schemes for the sensitivity analysis. For each criterion, six different weighting schemes were given and all the weightings of the other criteria were given equal weightings.

Table 7. 2 Weighting Schemes for the Suitability Criteria

Model Run	Soil %	Climate %	Slope %	Erosion %
1	10	30	30	30
2	25	25	25	25
3	40	20	20	20
4	55	15	15	15
5	70	10	10	10
6	85	5	5	5
7	30	10	30	30
8	25	25	25	25
9	20	40	20	20
10	15	55	15	25
11	10	70	10	10
12	5	85	5	5
13	30	30	10	30
14	25	25	25	25
15	20	20	40	20
16	25	25	55	25
17	10	10	70	10
18	5	5	85	5
19	30	30	30	10
20	25	25	25	25
21	20	20	20	40
22	25	25	25	55
23	10	10	10	70
24	5	5	5	85

Source: compiled by the author

7-2-3-1 Sensitivity analysis for Barley

The sensitivity analysis revealed that the soil is a highly sensitive in the suitability classification for barley. Figure 7.1 shows the land suitability classes for different weighting schemes. As can be noted, by increasing the influence of the soil criteria, the output suitability classes changed. When the soil weighting is 10 % two suitability classes can be observed. While, when soil weighting increased to 85 %, four suitability classes emerged. Increasing the soil weighting has a dramatic effect on the suitability pattern in the study area. By increasing the soil weighting to 85 % a significant proportion of the study area is classified as not suitable (NS) (26 %). Whereas there are no NS classes in the other soil weighting schemes. There are percentage weightings thresholds at which important changes to the relative proportions of S1, S2, and S3 take place. These percentages weighting are 55 %, 70 % and 85 % respectively.

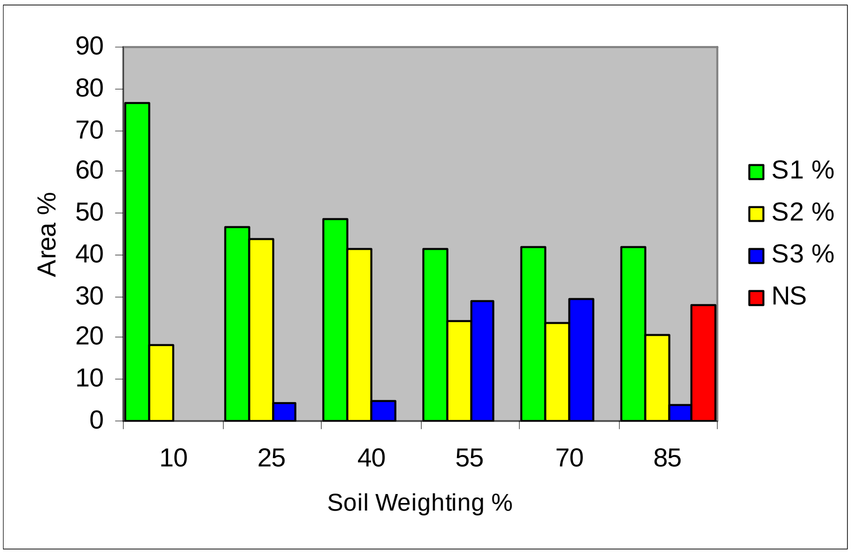


Figure 7. 5 Sensitivity analysis for Soil criteria (Barley) (for the remaining weighting see Table 7.2 from model run 1, 2, 3, 4, 5 and 6)

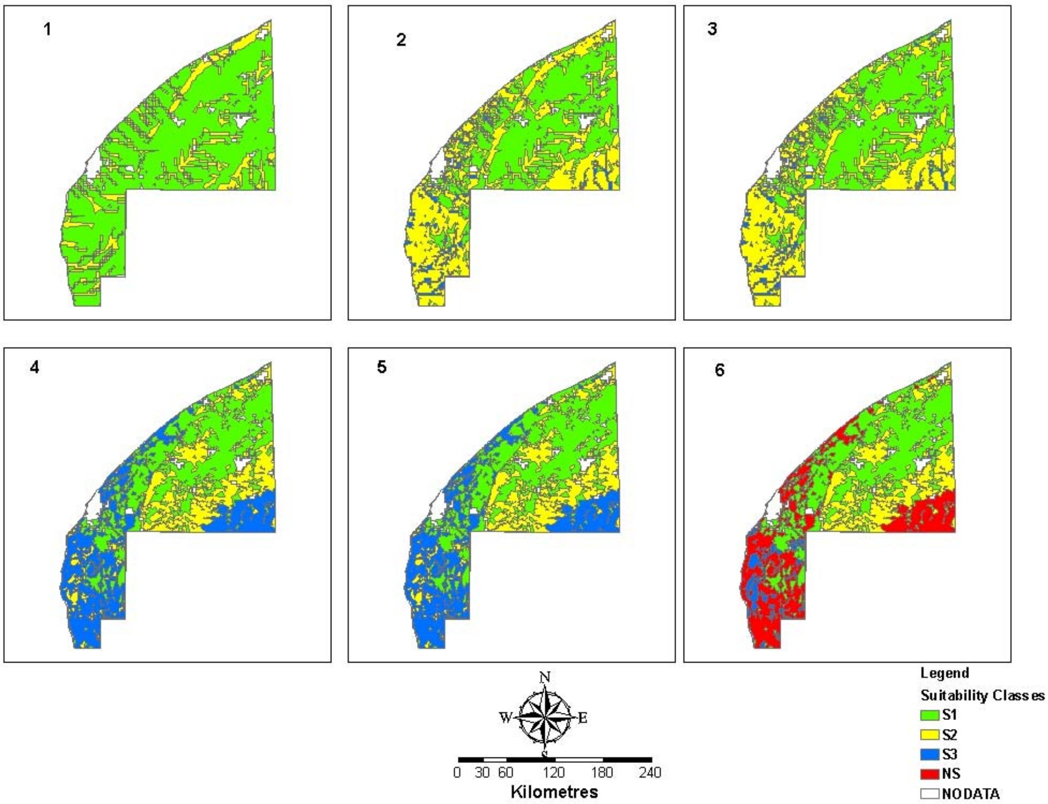


Figure 7. 6 Sensitivity analysis maps for soil (Barley) (soil weighting schemes, 1 = 10 %, 2 = 25 % , 3 = 40 %, 4 = 55 %, 5 = 70 % and 6 = 85 %)

The overall suitability classification was changed by the variation of soil weightings. This change is to be expected in the study area. As shown in the Figure 7.4, when the soil weightings increased, lower suitability ranks emerged from the parts of the study area where the production of barley is limited by soil salinity, soil depth and soil drainage. The implication of these findings is that soil factors have to be given suitable weighting reflecting its importance for the suitability of barley in the study area.

For the climate criteria, the sensitivity analyses indicated that the climate is highly sensitive. When the importance of climate was 10 %, the highly suitable class is 46.6 %, whereas by increasing the importance of climate to 40 % the highly suitable class is 57 %. The moderately suitable class (S2) is 42 % when the climate weighting is 10 %. Whereas it is 9.7 % when the climate weighting 55 %. The marginally suitable class (S3) is 6 % when the climate weighting is 10 % whereas there is no S3 when the climate weighting is 85 %.

The suitability pattern has changed by the change of the climate weighting. When the climate weighting is 10 %, three suitability classes can be observed, whereas, only one suitability class emerges when the climate weighting is 85 %. Climate is a highly sensitive parameter in the study area. This implies that climate has to be given a weighting reflecting its importance in the study area.

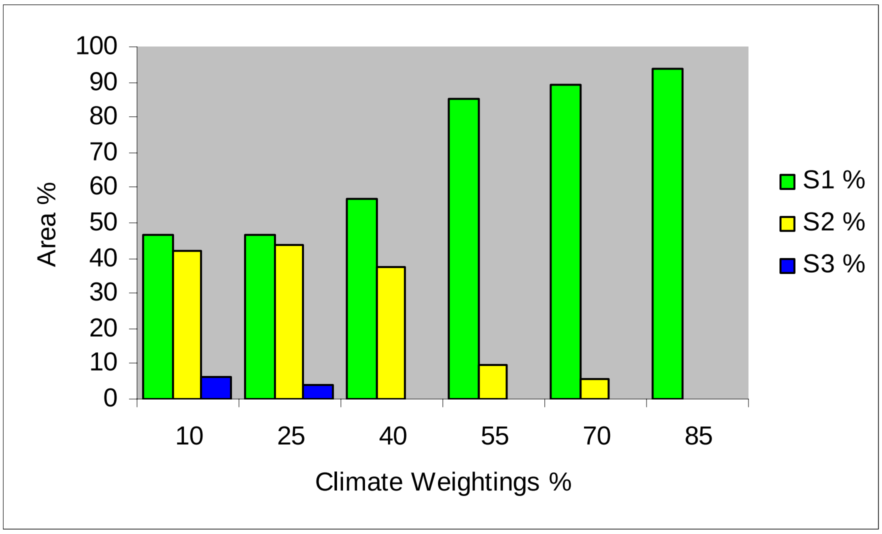


Figure 7. 7 Sensitivity analysis for Climate criteria (Barley) (for the remaining weighting see Table 7.2 model 7, 8, 9, 10, 11, and 12)

The sensitivity analysis for slope revealed that by changing the weighting schemes, the suitability pattern changes (Figure 7.6). However, the change is not as dramatic as in the soil case. When the slope weighting is 10 % a three suitability classes emerged and similarly when the slope weighting is 85 % three suitability classes can be observed. Therefore, in terms of the suitability pattern the slope weighting scheme has not greatly changed the outputs. However, the highly suitability class increases from 54 % to 75 % when the slope weighting increases from 10 % to 85 % respectively. In addition, the moderately suitable class decreases from 35 % to 15 % when the weighting of slope changes from 10 % to 85 %. The marginally suitable class also decreases from 5 % to 3 %.

These results suggested that the slope is not as sensitive as the soil and climate and therefore the weighting for each criterion should be different when the suitability model is used.

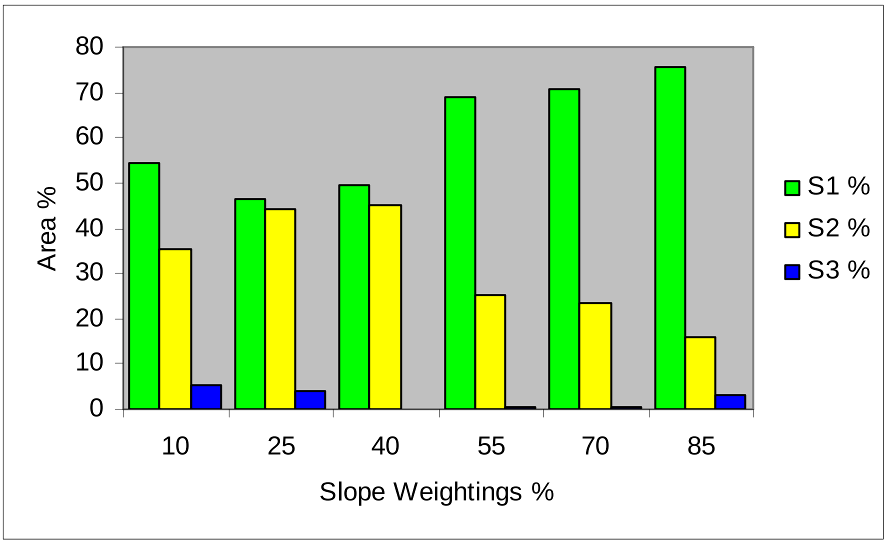


Figure 7. 8 Sensitivity analysis for Slope criteria (Barley) (for the remaining weighting see Table 7.2 from model run 13, 14, 15, 16, 17 and 18)

For the erosion, changing the weighting schemes resulted in change to the suitability outputs (Figure 7.7). The suitability pattern changed from three classes when the erosion weighting was 10 % to two classes when the erosion weighting was 85 %. The proportion of highly suitable class was 51.9 % when the weighting of erosion was 10 % and 82 % when the weighting of the erosion is 85 %. The moderately suitable classes is 12 % when the erosion weighting is 10 % while when the erosion weighting is 85 % there is no moderately suitable class (S2). The change in the suitability pattern indicates sensitivity of erosion in the study area.

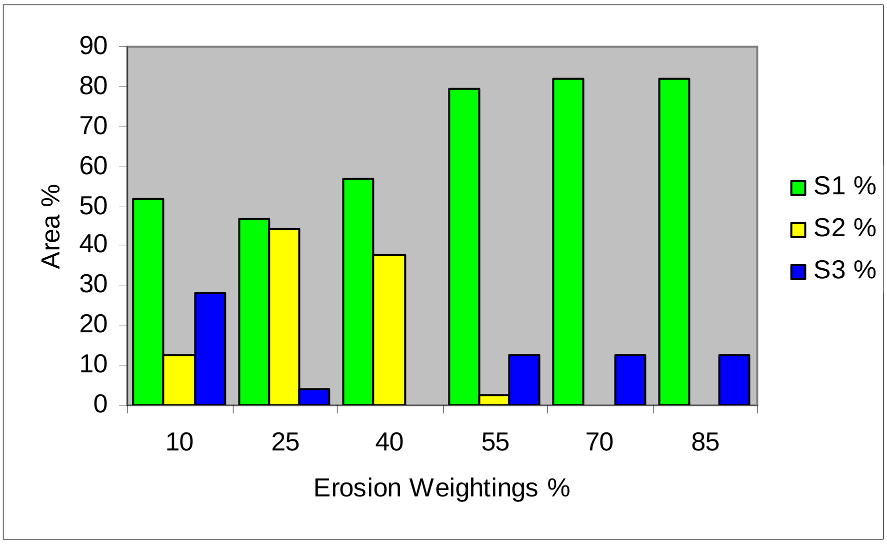


Figure 7. 9 Sensitivity analysis for Erosion criteria (Barley) (for the remaining weighting see Table 7.2 from model run 19, 20, 21, 22, 23, and 24)

The sensitivity analysis revealed that soil is the most sensitive criteria in the suitability classification for barely. The sensitivity analyses outputs show that the suitability pattern changed by the change in the soil weighting. Climate and erosion is the second sensitive criteria in the suitability.

This is to be expected because most of the study area is in Benghazi plain where the slope and erosion risk are low and the climate is suitable for barley. Therefore, the soil should be given suits its importance.

7-2-3-2 Sensitivity analysis for Wheat

The results from the sensitivity analysis indicate that suitability pattern changes with the variation in soil weighting. When the soil weighting was set 10 %, two suitability classes were observed. Equally four suitability classes emerged when the soil weighting was 85 % (Figure 7.8 and Figure 7.9).

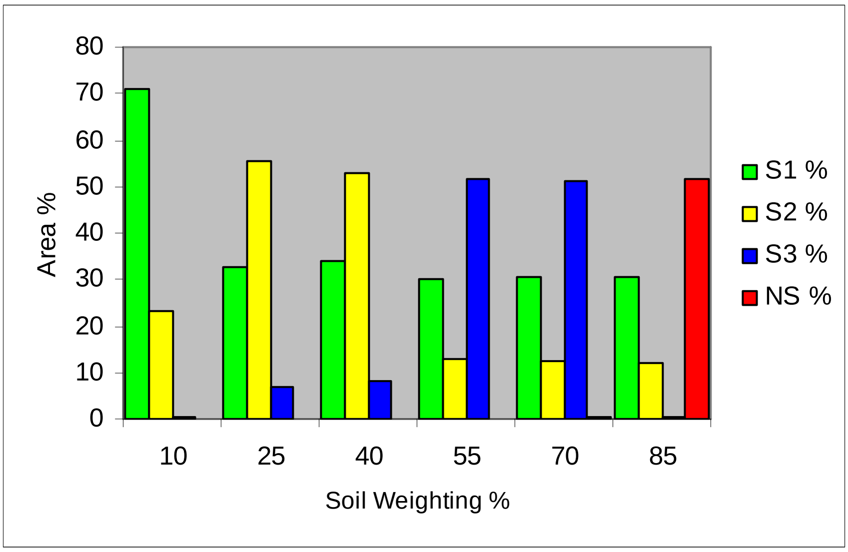


Figure 7. 10 Sensitivity analysis for Soil criteria (Wheat) (for the remaining weighting see Table 7.2 from model 1, 2, 3, 4, 5, and 6)

There were important variations in the suitability pattern when soil weighting increased. Four different suitability patterns can be recognised. The first pattern can be observed when the soil weighting was 10 %. The dominant class was highly suitable class (70 %). The second pattern occurred between the soil weighting 25 % and 40 %. These model runs produced a significant increase in the proportion of moderately suitable class. In addition, there was an increase in the marginally suitable class. The third pattern was observed when the soil weighting increased to 55 % and 70 %. The suitability classes were similar to pervious weighting i.e. there were three suitability classes. However, the results show a significant increase in the proportion of marginally suitable class (S3) (51 %). The fourth pattern appeared when the soil weighting increased to 85 %.

Four suitability classes were observed and the not suitable class (NS) was the dominant class in the weighting scheme. It can be concluded that these four variations in the suitability ranking indicate that the soil is a highly sensitive parameter in the study area.

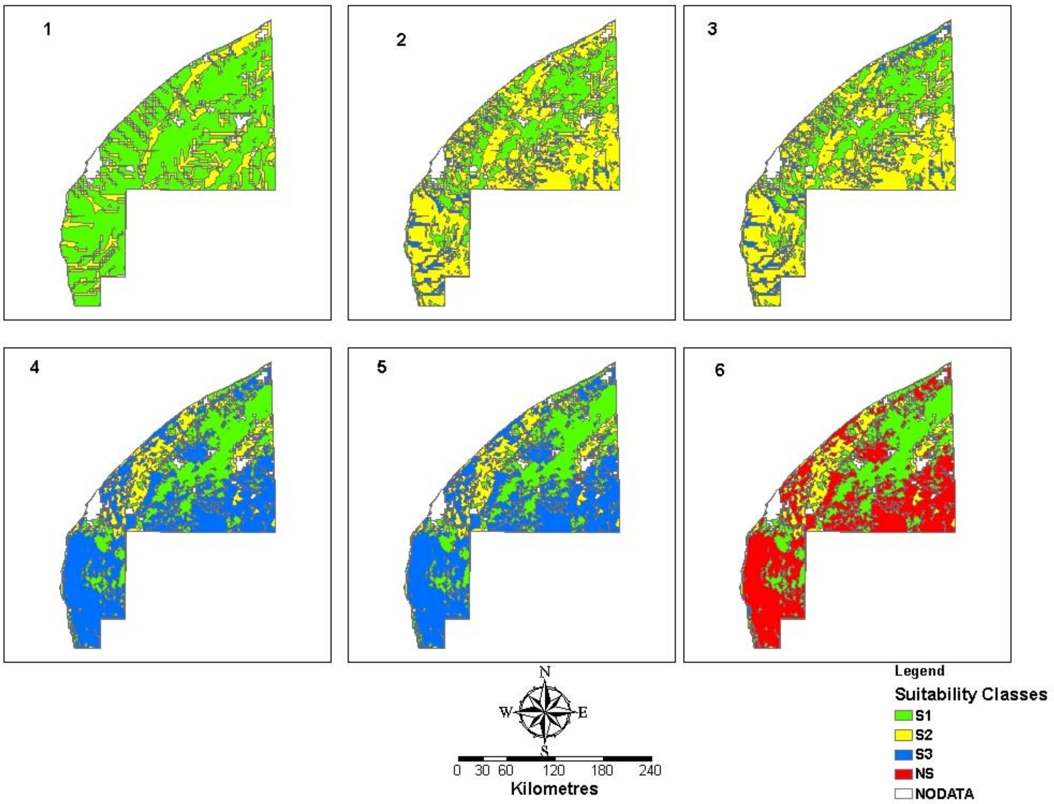


Figure 7. 11 Sensitivity analysis for Wheat (soil weighting schemes, 1 = 10 %, 2= 25 % , 3 = 40 %, 4 = 55 %, 5 = 70 %, 6 = 85 %)

Further tests were undertaken to establish how the suitability pattern changes by the variation of climate weightings (Figure 7.10). From the results, it appears that with increases in climate weighting, the proportion of highly suitable class increases. The increase was due to the fact that the climate is highly suitable for wheat in the study area.

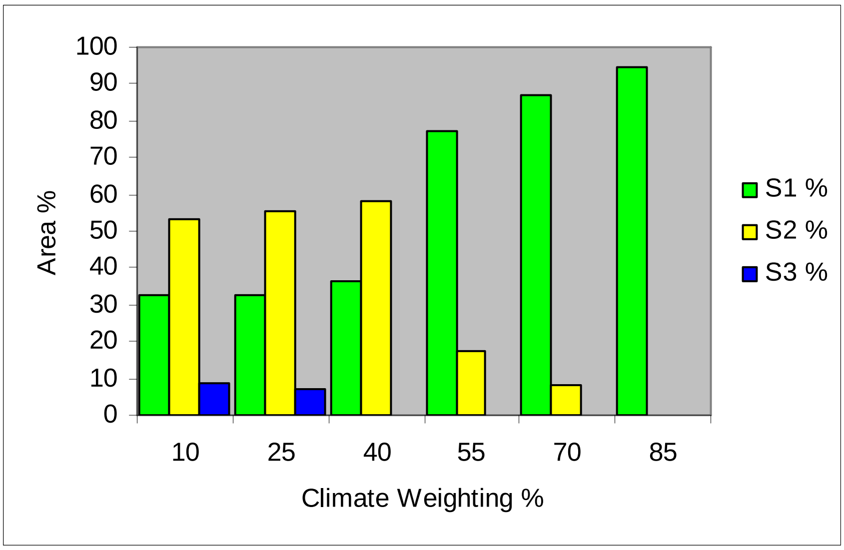


Figure 7. 12 Sensitivity analysis for Climate criteria (Wheat) (for the remaining weighting see Table 7.2 model 7, 8, 9, 10, 11, and 12)

The increase in climate weighting appears to favour the highly suitable class. For example, when the climate weighting was 10 %, the highly suitable area was 32 %, while when the climate weighting was 85 % the highly suitable class was 94 %. The suitability pattern greatly changed when the climate weighting increased to 55 %. The proportion of highly suitable class was double when the climate weighting increased to 55 % compared with the proportion of S1 in the pervious weighting (10 %, 25 %, and 40 %). From the results, it appears that climate is a highly sensitive parameter.

The variation of slope weighting produced two different suitability patterns. The first pattern was dominated by the moderately suitable class. The second suitability pattern was dominated by the highly suitable class (Figure 7.11). When slope weighting was set at 10 %, the resulting moderately suitable class was 51 %, while when slope weighting was 85 %, the highly suitable class was 75 %. Therefore, the slope does appears to influence the suitability ranking for wheat.

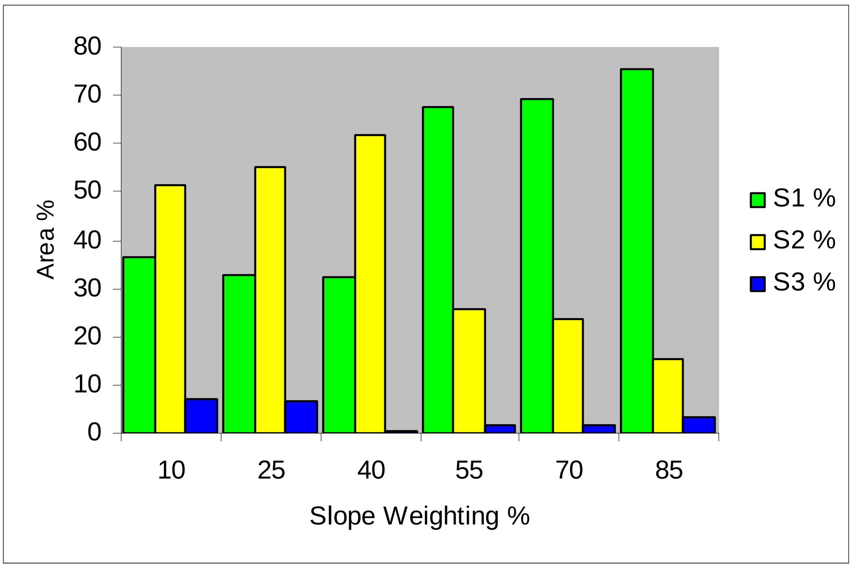


Figure 7. 13 Sensitivity analysis for Slope criteria (Wheat) (for the remaining weighting see Table 7.2 from model run 13, 14, 15, 16, 17, and 18)

For the erosion model parameter, the variations of the weighting schemes produced different proportion of the suitability classes. The moderately suitable class dominated the suitability pattern between an erosion weighting of 10 % to 40 %. While a significant proportion of study area, was highly suitable between erosion weightings of 55 % and 85 %.

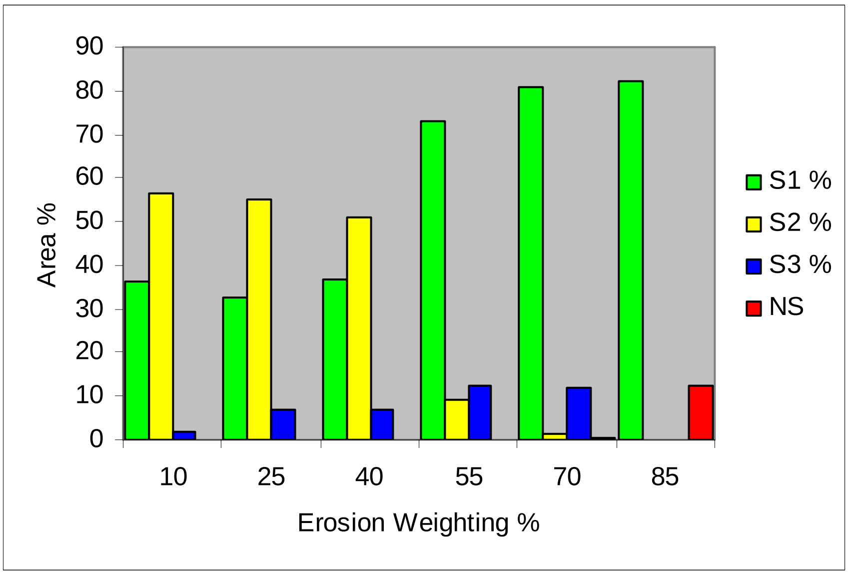


Figure 7. 14 Sensitivity analysis for Erosion criteria (Wheat) (for the remaining weighting see Table 7.2 from model runs 19, 20, 21, 22, 23, and 24)

The weighting schemes of soil, climate, slope, and erosion produced variations in suitability patterns. The weighting scheme of 55 % presents as the critical breaking point for climate, slope, and erosion. The change in the suitability pattern was towards an increase in the proportion of highly suitable land. Although a soil weighting of 55 % is also the breaking point in changing the suitability pattern, the change was toward an increase in the proportion of marginally suitable class. Most of the study area is in the Benghazi plain which has few limitations in terms of slope, climate, and erosion. Therefore, soil is considered highly sensitive in the study area and should correspondingly have a bigger weight than the other criteria.

7-2-3-3 Sensitivity analysis for Maize

The outputs of sensitivity analysis revealed important variations when the weighting of the suitability criteria were changed. When the soil weighting varied, four suitability patterns emerge by the changing of soil weighting (Figures 7.13 and 7.14). The first suitability pattern (soil weighting 10 %) was dominated by a highly suitable class. The second pattern occurred when the soil weighting was between 25 % and 40 %. Three suitability classes can be observed in this pattern. The third suitability rank pattern emerged when the soil weighting increased to 55 % and 70 %. Despite the similarity between the second and third pattern, the main difference was the increase of the marginally suitable class in the third pattern. The marginally suitable class was 5 % in the second pattern (soil weighting between 25 % and 40 %), whereas it was 30 % when in the third suitability pattern (soil weighting between 55 % and 70 %).
The fourth suitability pattern took place when soil weighting was 85 %. In this weighting scheme, a significant proportion of the study area was not suitable for maize and there was no land classes as marginally suitable. These suitability

patterns suggest that soil is a highly sensitive parameter for the suitability of maize.

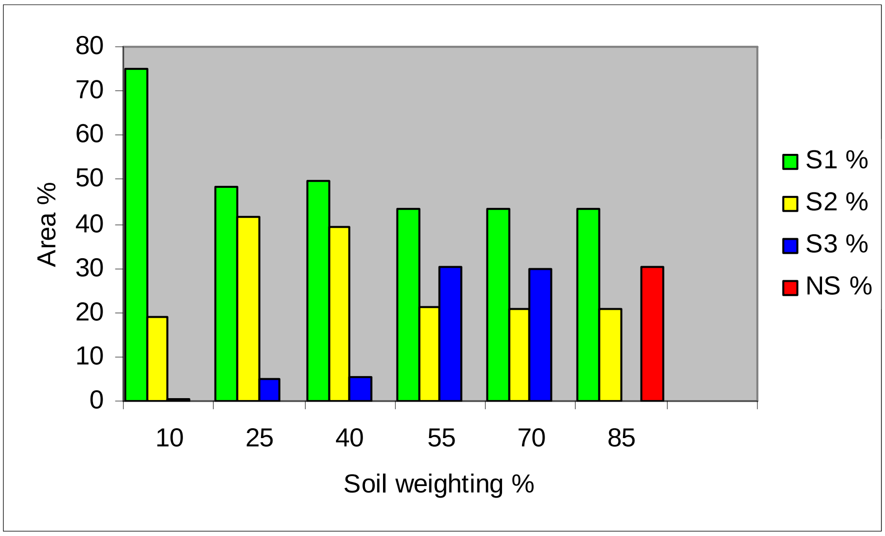


Figure 7. 15 Sensitivity analysis for Soil criteria (Maize) (for the remaining weighting see Table 7.2 from model runs 1, 2, 3, 4, 5 and 6)

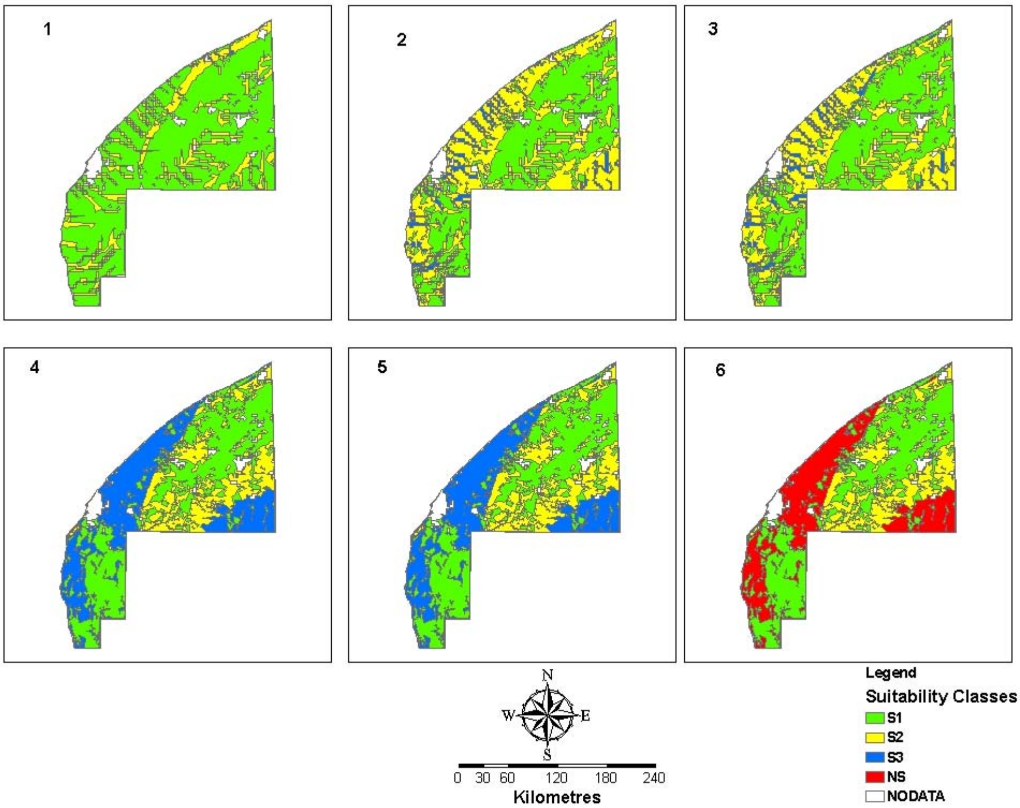


Figure 7. 16 Sensitivity analysis for Maize (soil weighting schemes, 1 = 10 %, 2 = 25 % , 3 = 40 %, 4 = 55 %, 5 = 70 % and 6 = 85 %)

For climate, the analysis indicated an increase in the highly suitable class area (S1) with the increase in the weighting of climate. When the weightings of climate were 10 %, 25 %, 40 %, 55 % and 85 %, the highly suitable class, (S1), corresponding were 48 %, 48 %, 61 %, 84 %, and 89 % (Figure 7.15). The suitability patterns show an increase in the highly suitable class and decrease in the moderately and marginally suitable class.

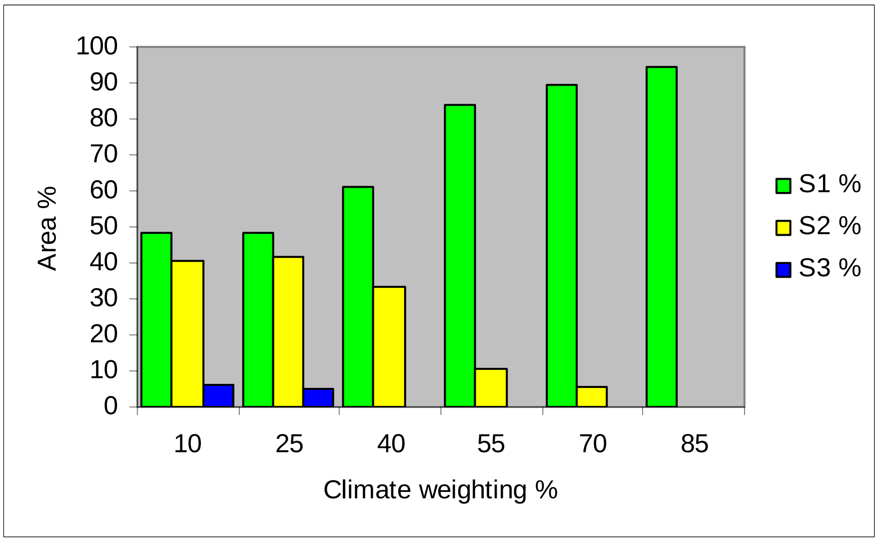


Figure 7. 17 Sensitivity analysis for Climate criteria (Maize) (for the remaining weighting see Table 7.2 model runs 7, 8, 9, 10, 11, and 12)

For the slope, the sensitivity analysis revealed that the increase in slope weighting affected the suitability pattern of maize (Figure 7.16). The increase in slope weighting increased the percentage of the highly suitable class in the study area. There were two suitability patterns emergent given the increase of slope importance in the model. The first pattern showed a comparable proportion of the highly and moderately suitable classes (from slope weighting 10 % to 40 %). The threshold value of the second pattern was the slope weighting 55 %. From this weighting, a significant proportion of the study area was of a highly suitable class.

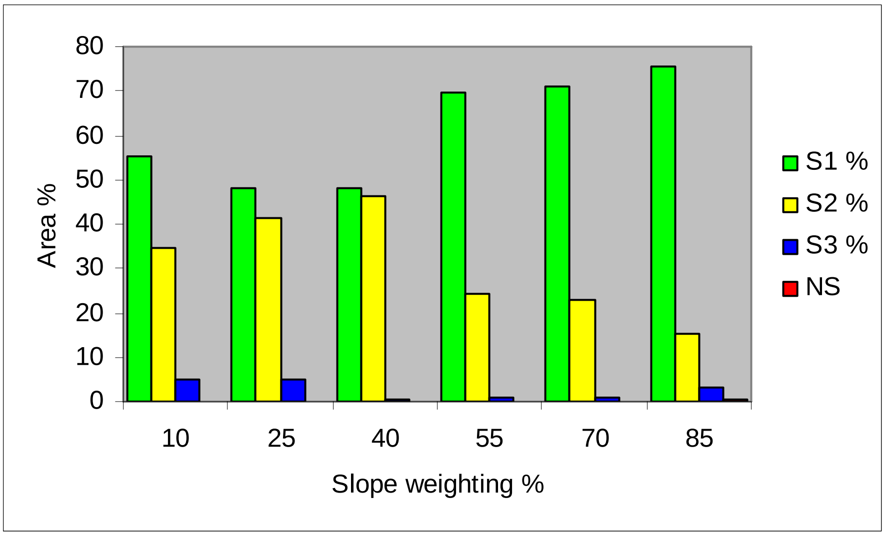


Figure 7. 18 Sensitivity analysis for Slope criteria (Maize) (for the remaining weighting see Table 7.2 from model runs 19, 20, 21, 22, 23, and 24)

The outputs of the sensitivity analysis for erosion demonstrate three different suitability patterns (Figure 7.17). The first suitability patterns consisted of three suitability classes, namely, highly, moderately and marginal classes. The second patterns threshold value gave an erosion weighting of 55 %.

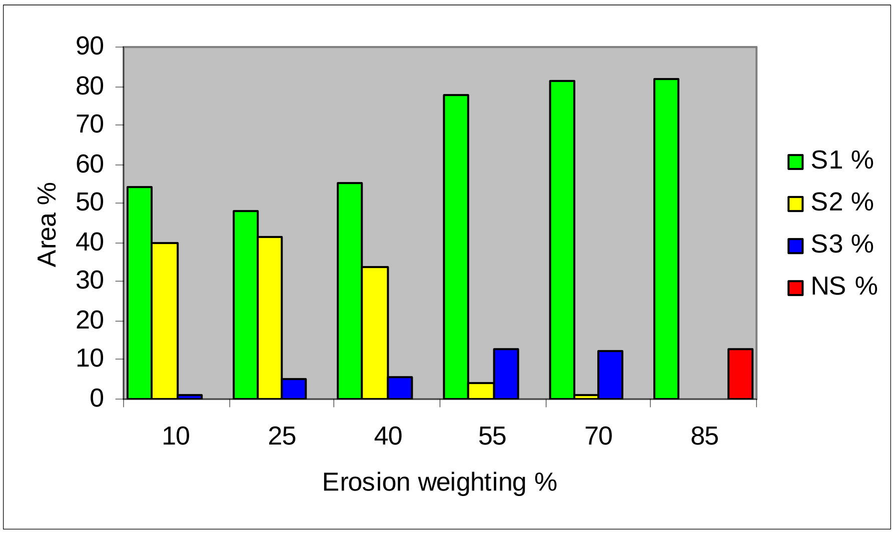


Figure 7. 19 Sensitivity analysis for Erosion criteria (Maize) (for the remaining weighting see Table 7.2 from model runs 19, 20, 21, 22, 23, and 24)

When the slope weighting was 55 %, the highly suitable class increased and the marginally suitable class decreased. The third suitability pattern appeared when the erosion weighting was 85 %. Two suitability classes appeared in this slope weighting. The not suitable class appeared and it was 12.8 %.

The weighting schemes of the suitability criteria revealed that the break threshold value of the suitability patterns was when those criteria are weighted to 55 %. In general, The increase in the weighting of climate, slope, and erosion caused an increase in the proportion of highly suitable class. Equally, the increases in soil weighting decreased the highly suitable classes and increased the proposition of moderately and marginally suitable classes. In addition, when the soil weighting was increased to 85 %, a significant proportion of the study area was found not suitable for maize.

In conclusion, soil is a highly sensitive in the study area. Therefore, it should be weighted accordingly. This is true for the study is where the climate, slope, and erosion all appear to be highly suitable for maize. However, if the model is to be used elsewhere in the future, further analyses are needed to investigate the appropriate weighting for the suitability criteria.

7-2-3-4 Sensitivity analysis for sorghum

The outputs of sensitivity analysis for sorghum indicated how the suitability patterns changed with the variations of the weighting schemes (Figure 7.18 and Figure 7.19). For soil, there were significant changes in the relative proportion of suitability classes when the soil weighting changes. Three suitability patterns can be observed when the soil weighting increased. The first pattern occurred when soil weighting was between 10 % and 40 %. Here, the result was dominated by the highly suitable class. The second pattern emerged when the soil weighting between 55 % and 70 %. The percentage of S3 increased whereas the proportion of S2 decreased.

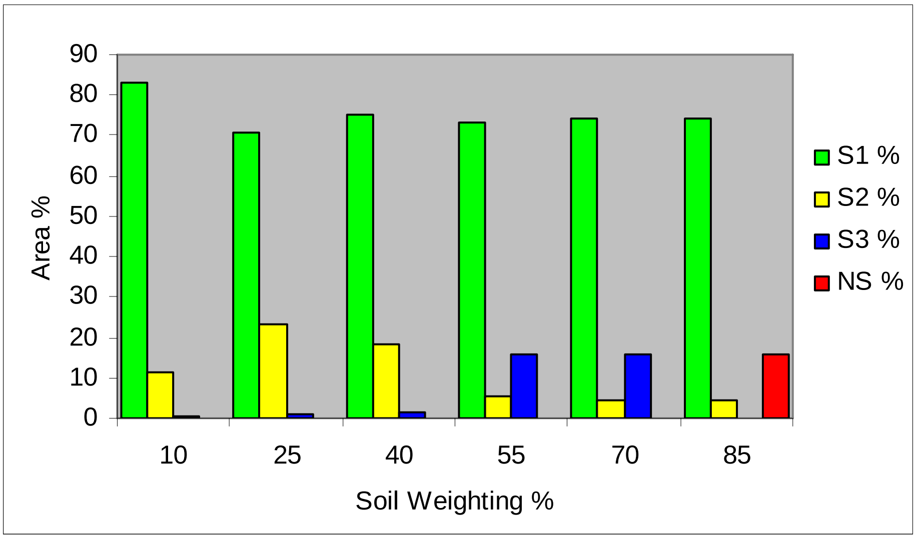


Figure 7. 20 Sensitivity analysis for Soil criteria (Sorghum) (for the remaining weighting see Table 7.2 from model runs 1, 2, 3, 4, 5, and 6)

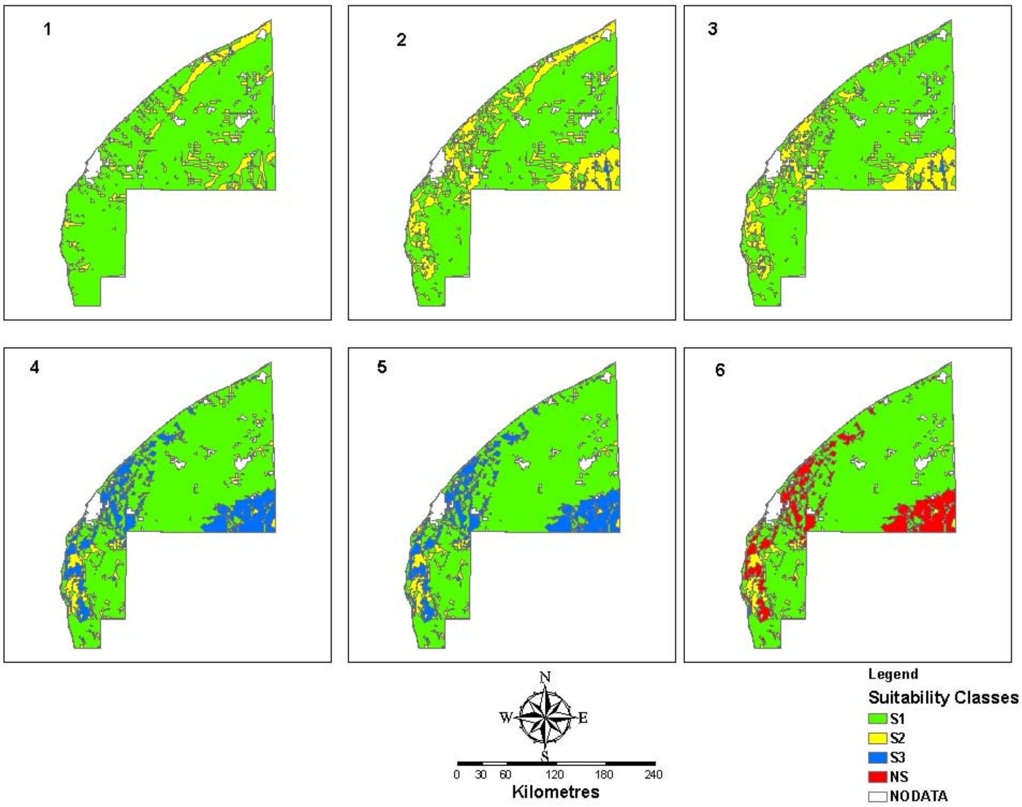


Figure 7. 21 Sensitivity analysis for Sorghum (soil weighting schemes, 1 = 15 %, 2 = 25 % , 3 = 30 %, 4 = 40 %, 5 = 50 %, 6 = 60 % and 7 = 70 %)

The third suitability pattern took place when the soil weighting was 85 %. The most important change in this pattern was the appearance of not suitable (NS) instead of marginally suitable (S3). This confirms that soil is a sensitive in suitability parameter for sorghum.

For climate, the sensitivity analysis showed a variation in the suitability outputs (Figure 7.20). Three suitability patterns can be recognised. The first suitability pattern was observed when the climate weighting was between 10 % and 25 %. The second suitability pattern emerged when the climate importance was between 55 % and 70 %. The third suitability pattern took place when the climate weighting was 85 %. The proportion of the highly suitable class overall was 94 %.

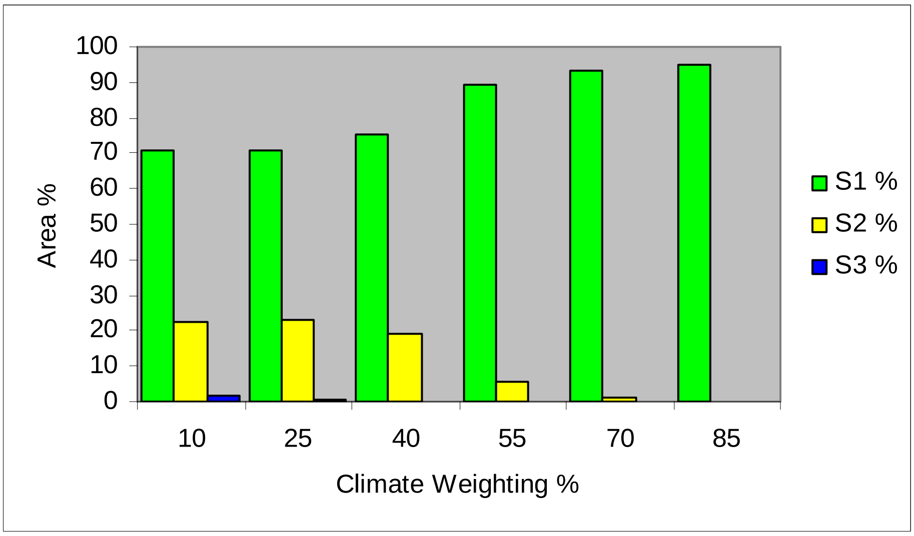


Figure 7. 22 Sensitivity analysis for Climate criteria (Sorghum) (for the remaining weighting see Table 7.2 model runs 7, 8, 9, 10, 11, and 12)

The sensitivity analysis for the slope revealed that there is only a slight change in the suitability pattern when the slope weighting varied (Figure 7.21). A significant proportion of resultant highly suitable class was observed when slope weighting increased to 85 %. In addition, three suitability classes emerged.

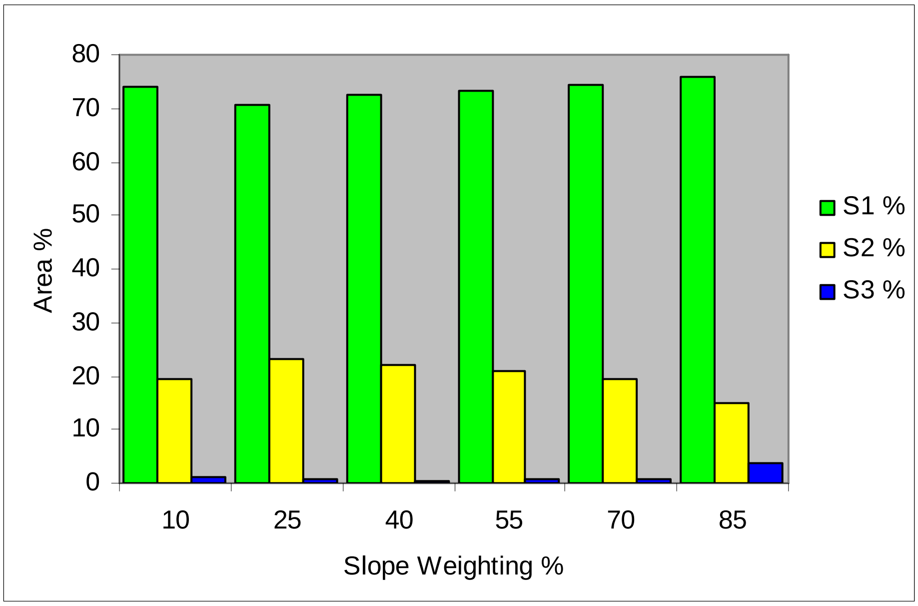


Figure 7. 23 Sensitivity analysis for Slope criteria (Sorghum) (for the remaining weighting see Table 7.2 from model runs 19, 20, 21, 22, 23, and 24)

For erosion, the sensitivity analysis revealed that there were slight changes in the suitability pattern with the variation of erosion weighting (Figure 7.22). Three suitability patterns can be recognised when the weighting of erosion increased.

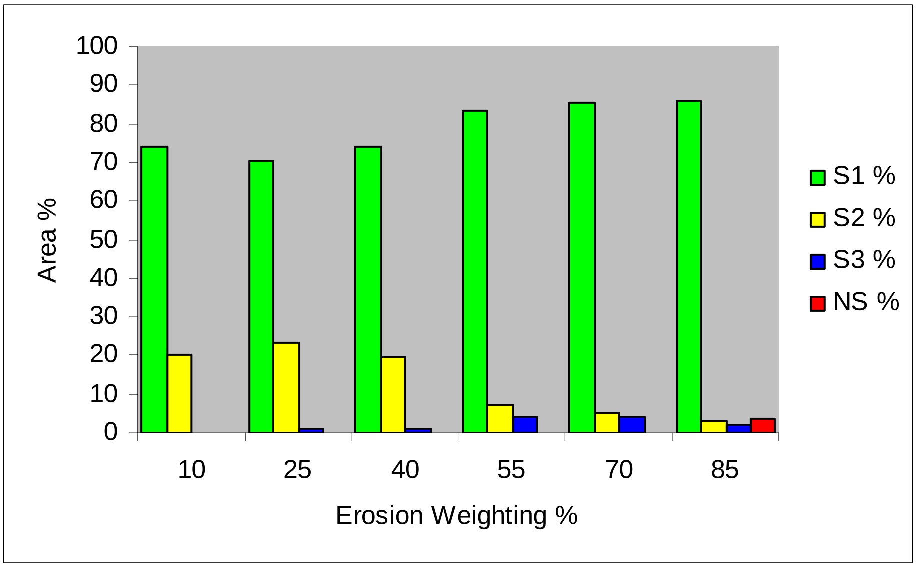


Figure 7. 24 Sensitivity analysis for Erosion criteria (Sorghum) (for the remaining weighting see Table 7.2 from model runs 19, 20, 21, 22, 23, and 24)

The first suitability pattern can be observed when the erosion weighting was between 10 % and 40 %. The second pattern emerged when the erosion weighting was between 55 % and 70 %. The third occurred when the erosion weighting increased to 85 %. There were slight changes in the proportion of the highly suitable class across the range of the weightings. The change was from S2 to S3 and / or to NS. Most of the study area is located in low risk of erosion and small part of it is at risk of erosion hazard. Therefore, by increasing the erosion weighting the moderately suitable classes downgraded to the lower suitability classes (S3 and NS).

The sensitivity analysis of the suitability criteria for sorghum revealed that soil is highly sensitive in the study area. It should be given the highest weighting. The second most sensitive criterion is climate. These findings should influence the implementation of the suitability model in the study area. The findings highlighted the fact that soil and climate should be given the highest importance respectively then erosion and slope in the study area.

7-2-4 Sensitivity Analysis for Land Characteristics

A sensitivity analysis examines the model sensitivity to variation in input parameters where each individual input parameter is decreased and increased systematically to analyse its effect on model outputs whilst keeping other parameters unchanged. The aim of the sensitivity analysis for the land characteristics is to test the threshold values and address the uncertainty. The sensitivity analysis was conducted by changing one land characteristic and leaving the other land characteristics unchanged. This can be achieved both through the variation of the thresholds adopted for each characteristic, and also through variation of the proportionality assigned to each characteristic in its combination with the others – or rather its weighting. The sensitivity analysis explained in this chapter addresses both these approaches leading to a greater robustness and confidence being attributable to the final model framework.

In the following sections, the threshold values for each land characteristic were increased and decreased in turn to address the uncertainty that exits in the limits between suitability classes. This was done for all land characteristics and an example was given of each criterion (climate, soil, erosion and slope). The full sensitivity analysis scenarios and results are given in details in Appendix E.

7-2-4-1 Sensitivity Analysis for Climate Criteria (Temperature)

The sensitivity analysis for temperature as a land characteristic was conducted in order to address the uncertainty of the limits between suitability classes. The threshold values selected in Chapter Five for temperature for each crop were systematically changed (Table 7.3). Seven scenarios were run in the model, the outputs were visually assessed, and the area for each land suitability class was calculated. The outputs of the sensitivity analysis for each crop are introduced in Appendix E2 (E2-1, E2-2, E2-3, and E2-4).

Table 7. 3 Scenario for sensitivity analysis of climate

Scenarios	Thresholds values ° C
1	- 6
2	- 4
3	- 2
4	Threshold value
5	+ 2
6	+ 4
7	+ 6

Source: (developed by the author)

The sensitivity analysis of temperature threshold values for the barley revealed a significant change in the suitability pattern when the threshold changes (Figure 7.23). Three suitability classes emerged when the limits between classes decreased by 2 °C, 4 °C and 6 °C. The dominant suitability class when the temperature decreased appears as the moderately suitability class. The default threshold value appears to exhibit a similar suitability pattern. However, the highly and moderately suitable classes have a comparable proportion of the study area. This was the same when the threshold values increased by 2 °C.

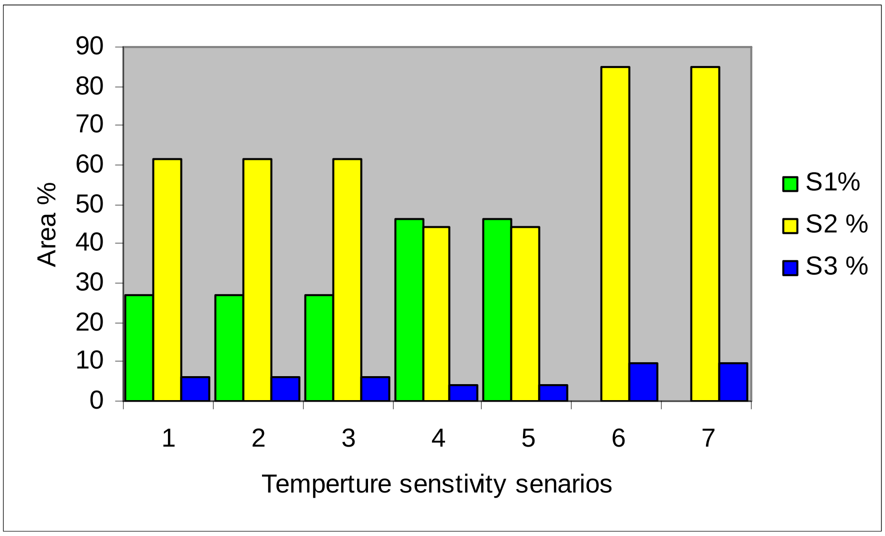


Figure 7. 25 Sensitivity analysis of Temperature for Barley (see Table 7.3 for codes)

When the threshold values were increased by 4 °C and 6 °C, the suitability pattern changed. Two suitability classes emerged (S2 and S3) and a significant proportion of the study area was a moderately suitable class. The suitability for barley was sensitive for the lower temperature.

The sensitivity analysis shows that the temperature is a sensitive land characteristic and that it can affect the overall suitability. These results give more confidence in the threshold values.

The results of the analysis for wheat are shown in Figure 7.24. The suitability pattern changed when the threshold values were increased by 4 °C and 6 °C. Two suitability classes emerged following this increase whereas from the remaining scenarios, the suitability patterns remained unchanged.

The proportion of the highly suitable class was the highest when the threshold values were in scenario 4 (threshold value default) and scenario 5 (2 °C).

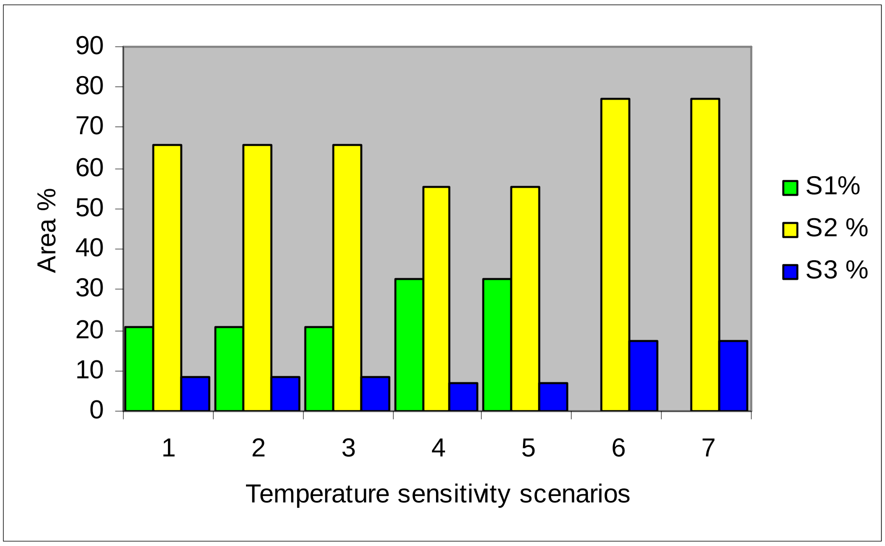


Figure 7. 26 Sensitivity analysis of Temperature for Wheat (see Table 7.2 for codes)

A pattern of relative changes in the proportion of each suitability class emerged when the threshold values changed. For example, the highly suitable class was approximately 20 % in scenario 1, 30 % in scenario 4, and 0 % in scenario 6. The results show that the temperature is a sensitive land characteristic and this gives a confidence to the threshold values.

For maize, the sensitivity analysis revealed that temperature is sensitive to land characteristics. There were patterns revealed relative changes in proportions of the suitability classes (Figure 7.25). Four suitability patterns can be observed when the temperature threshold values increased and decreased from the default threshold values. When the limits of temperature were decreased by 6 °C, only two suitability classes emerged. The dominant class revealed was moderate. The second pattern appeared when the threshold values were decreased to 2 °C and 4 °C. Three suitability classes emerged (S1, S2 and S3). The proportions of marginally and moderately suitable classes decreased. The proportion of highly suitable land increased to approximately 30 %. The third suitability pattern appeared in scenarios 4, 5 and 6. The highly and moderately suitable classes had a comparable proportion. The fourth suitability pattern emerged in scenario 7. There was no highly suitable class in this suitability pattern.

In conclusion, the suitability classes strongly affected when the temperature threshold increased or decreased by 6 °C. The decrease of the threshold values of temperature affected the suitability ratings more than the increase. For example, when the threshold values decreased by 2 °C (scenario 3), the suitability rating sharply change (Figure 7.25). Whereas when the threshold values increased by 2 °C (scenario 5), the suitability rating did not change. This was equally applicable for the increase and the decrease in threshold values by 4 °C.

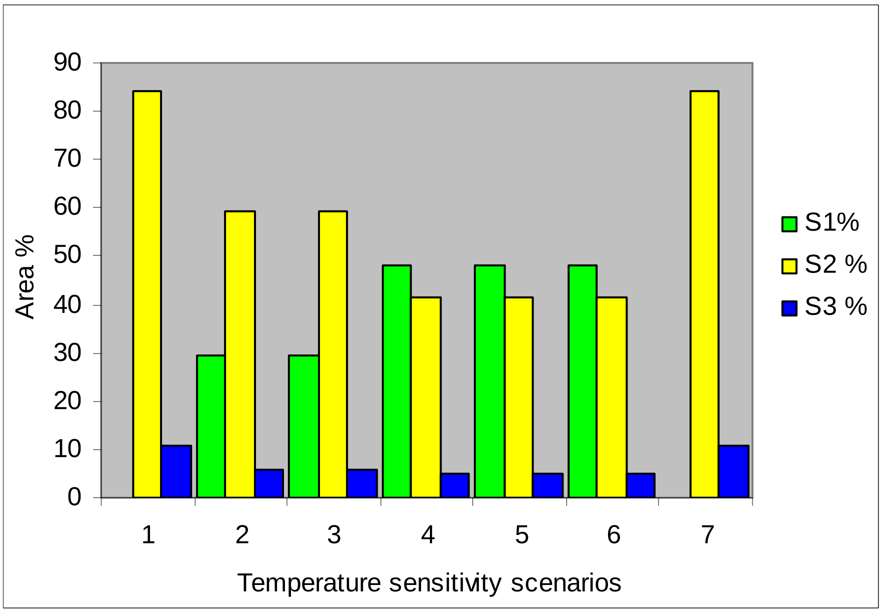


Figure 7. 27 Sensitivity analysis of Temperature for Maize (see Table 7.2 for codes)

For sorghum, the suitability classification showed a pattern of changes by the variation of the threshold values of temperature (Figure 7.26). Different suitability pattern can be observed when the threshold values changed according to scenarios in Table 7. 3. When temperature threshold value decreased by 6 °C (scenario 1), S2 and S3 emerged. When the temperature threshold values increased by 6 °C (scenario 7), three suitability emerged.

In conclusion, the analysis showed that the suitability classes strongly affected when the threshold values were decrease by 4 °C and 6 °C, whilst the change were slight when the threshold values were increased by 4 °C and 6 °C. In addition, the findings revealed that by increasing or decreasing the temperature threshold values by 2 °C, the suitability rating do not change.

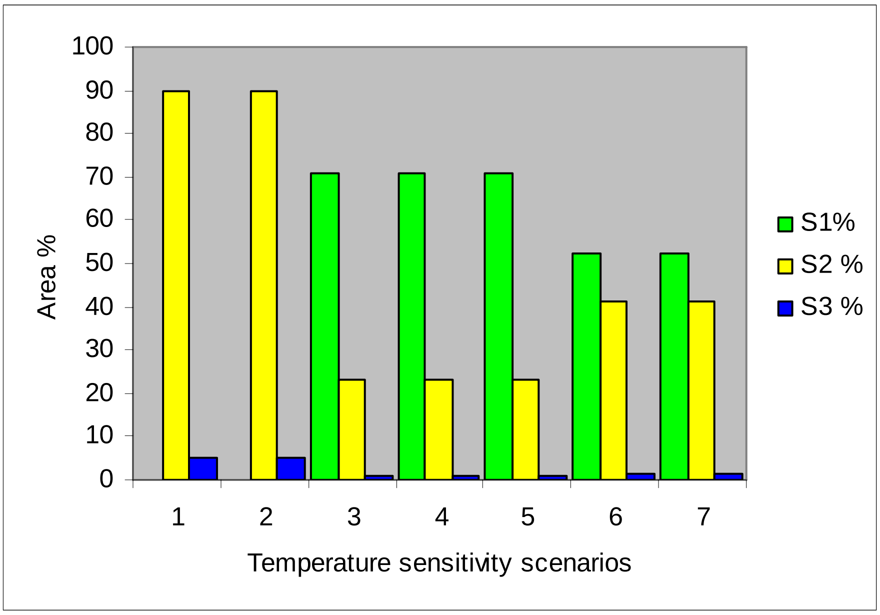


Figure 7. 28 Sensitivity analysis of Temperature for Sorghum (see Table 7.3 for codes)

7-2-4-2 Sensitivity Analysis for Slope

Seven different scenarios were designed to conduct the sensitivity analysis (see Table 7.4). The land suitability model was run with new threshold values to produce the corresponding land suitability outputs. These outputs are represented in suitability maps for each crop. Visual assessment and area calculations of the output maps were used to compare the scenarios. The full threshold values of the seven scenarios and the results of the area calculation for each crop can be viewed in Appendix E (E3-1, E3-2, E3-3, and E3-4).

Table 7. 4 Scenarios of slope sensitivity analysis

Scenario	Threshold value %
1	- 1.5
2	- 1
3	- 0.5
4	Default threshold values
5	+ 0.5
6	+ 1
7	+ 1.5

For barley, the sensitivity analysis for slope indicated that the slope is moderately sensitive land characteristic. When the threshold values of slope were increased, the overall suitability of barley slightly changed (Figure 7.27). The change was a slight increase in the proportion of highly suitable class.

While when the threshold values decreased, there were gradual changes in the suitability. The change was an increase in the proportion of moderately suitable class. Scenario 4 (default threshold value) was the breaking point where the proportion of highly suitable class became greater than the moderately suitable class. The percentage of highly suitable class increased from 17.5 % in scenario 1 to 53.9 % in scenario 7. This confirms that the model response to the change in the threshold value and the default threshold values is the breaking point where important changes in the suitability classes take place.

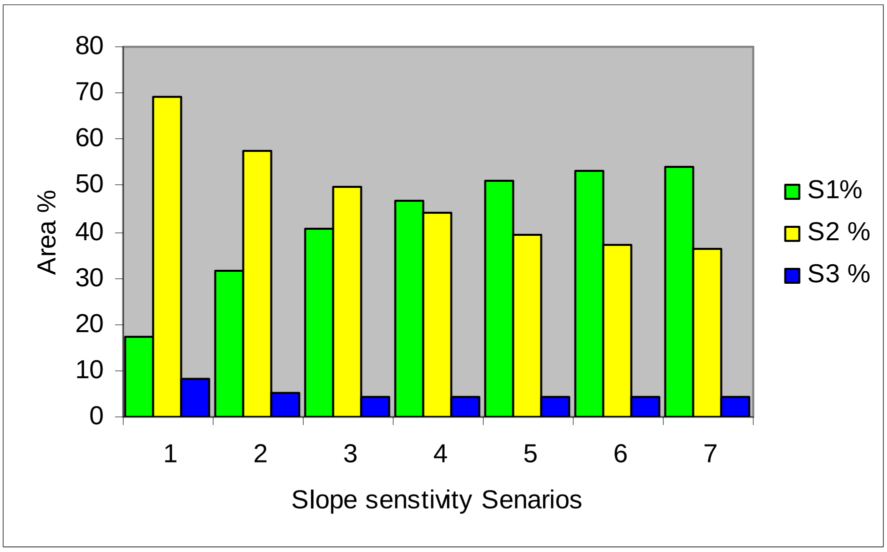


Figure 7. 29 Sensitivity analysis of Slope for Barley (see Table 7.4 for codes)

For wheat, the suitability pattern slightly changed through the variation of the threshold values of slope. The change in the suitability rating was greater when the threshold values were decreased. The percentage of the highly suitable class was 13.2 % in scenario 1, whilst it was 36 % in scenario 7. In addition, the percentage of moderately suitable class was 65 % in scenario 1, whereas it was 51 % in scenario 7. Therefore, slope is a sensitive land characteristic in the study area.

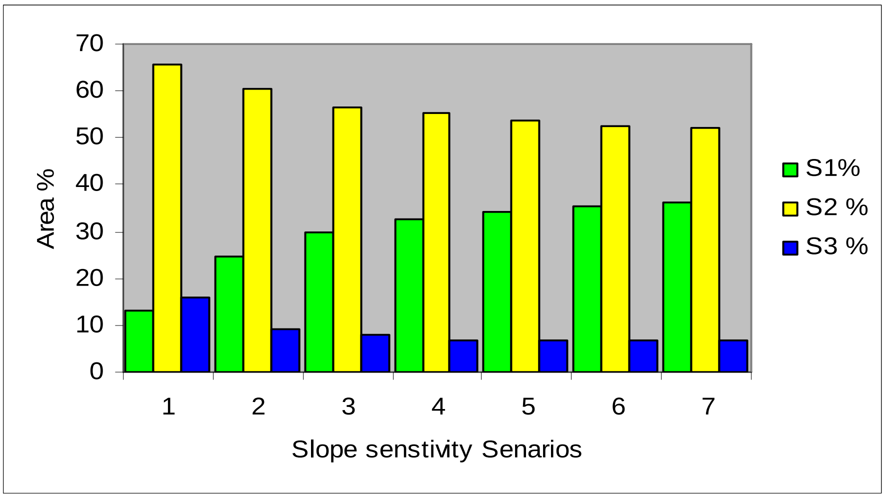


Figure 7. 30 Sensitivity analysis of Slope for Wheat (see Table 7.4 for codes)

For maize, the sensitivity analysis revealed that there was a slight change in suitability patterns when the threshold values of slope changed (Figure 7.29). The change was greater when the threshold values were decreased. When the threshold values were decreased the proportion of moderately suitable class increased (scenarios 1, 2 and 3). Conversely, when the threshold values decreased the highly suitable class increased (scenarios 5, 6 and 7). The percentage of S2 was 62.7 % when the threshold values were as described in scenario 1. The percentage of S2 was 34.7 % in scenario 7.

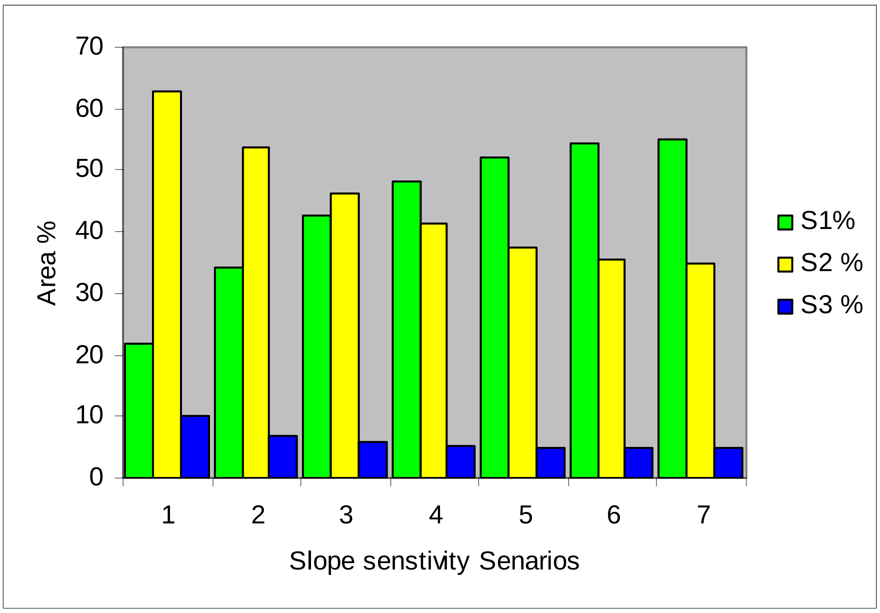


Figure 7. 31 Sensitivity analysis of Slope for Maize (see Table 7.4 for codes)

For sorghum, the results from the sensitivity analysis revealed that slope is a sensitive land characteristic. When the threshold values decreased, the suitability patterns changed (Figure 7.30). By example, the proportion of S2 was 73 % in scenario 1 whereas it decreased to 20 % in scenario 7. Two suitability patterns emerged when the slope threshold values changed. The first pattern was in scenario 1 and 2. This suitability pattern showed a significant proportion of the study area was S2. The second suitability pattern occurred from scenarios 3 and 4 and continued through the remaining scenarios. This pattern showed a significant percentage to be S1. This can be explained in that most of the study area is located in Benghazi plain. Therefore, the variation in the suitability is to be excepted when the threshold values are decreased.

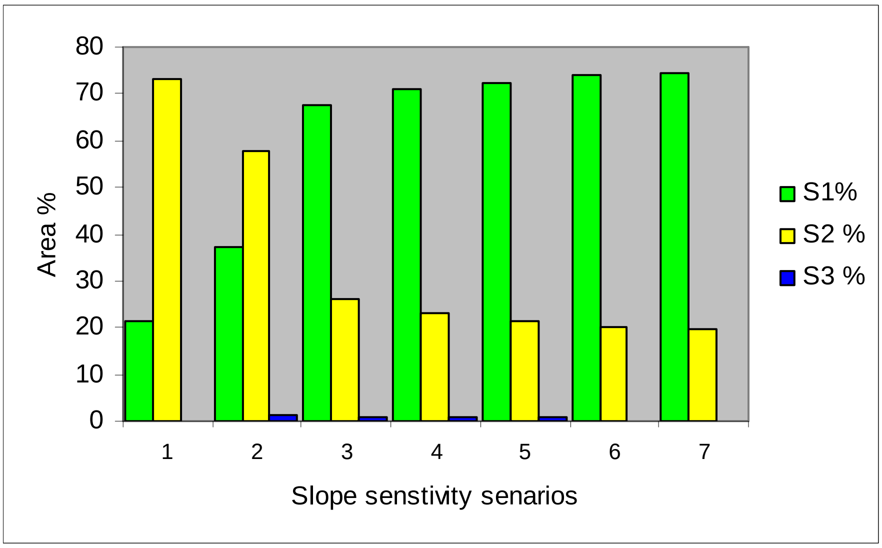


Figure 7. 32 Sensitivity analysis of Slope for Sorghum (see Table 7.4 for codes)

7-2-4-3 Sensitivity Analysis for Erosion Criteria

The sensitivity analysis for erosion was conducted by systematically changing the threshold values. The scenarios were tested and the results presented and displayed in Appendix E (E4-1, E4-2, E4-3 and E4-4).

The results from the sensitivity analysis suggested that erosion hazard is not sensitive characteristic. The results showed that the change of threshold values slightly varied the corresponding suitability patterns in all crops.

For barley, the suitability patterns showed no change when the threshold values increased (Figure 7.31). When the threshold value decreased, the suitability did not change for the first decrease (scenario 1). When the threshold values decreased further, there were slight changes in the suitability pattern. The marginally suitable class appeared in the suitability pattern. However, there were no strong changes in the proportion highly suitable class and moderately suitable class.

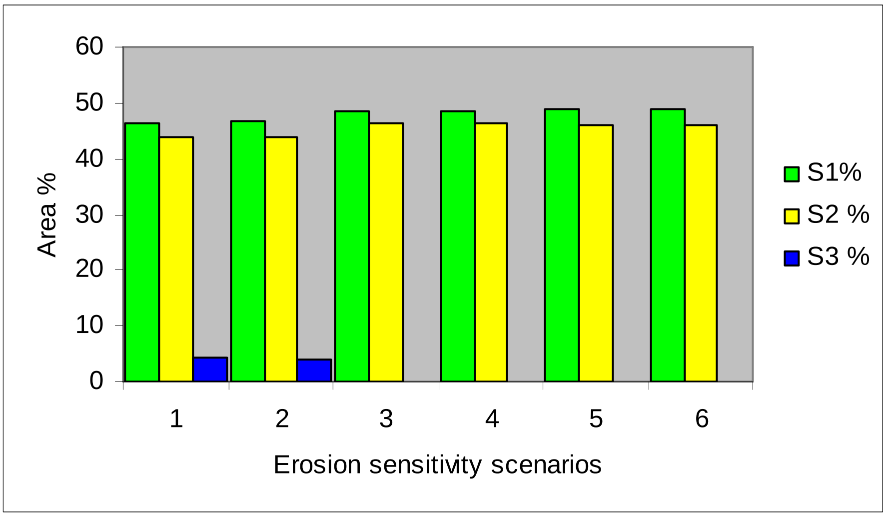


Figure 7. 33 Sensitivity analysis of Erosion for Barley

For wheat, the decrease in the threshold values of erosion (scenario 3) did not change the overall suitability pattern. However, when the threshold values decreased further (scenario 1 and 2), the suitability patterns strongly changed. The marginally suitable class emerged, and the proportion of the highly suitable class decreased and moderately suitable class increased. (Figure 7.32). When the threshold values increased in scenario 5 and 6, two suitability classes emerged. A significant percentage of the suitability classes were highly suitable class. The results showed that wheat exhibited the most variations in response to the change in threshold values. It showed that scenario 3 and 4 are the breaking points in the suitability patterns.

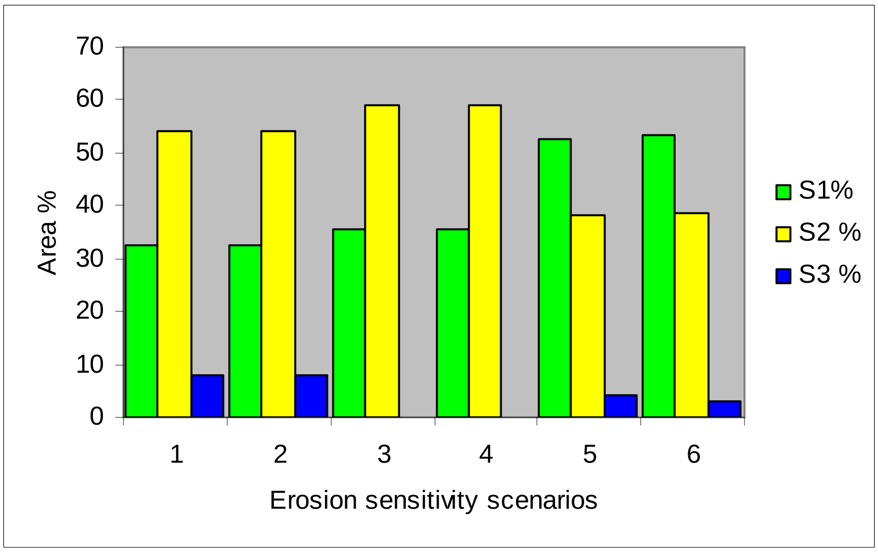


Figure 7. 34 Sensitivity analysis of Erosion for Wheat

For maize, the results of the sensitivity analysis showed clear changes in the suitability pattern (Figure 7.33). The increasing of threshold values from the default threshold value show no change in the suitability patterns. However, the decrease of the threshold values showed a slow change in the suitability pattern. These changes were a small decrease in the proportion of highly suitable class and moderately class and an increase in the marginally suitable class. This confirms that the erosion is not a sensitive land characteristic in the study area for wheat and showed little changes in the overall suitability when the threshold values changes.

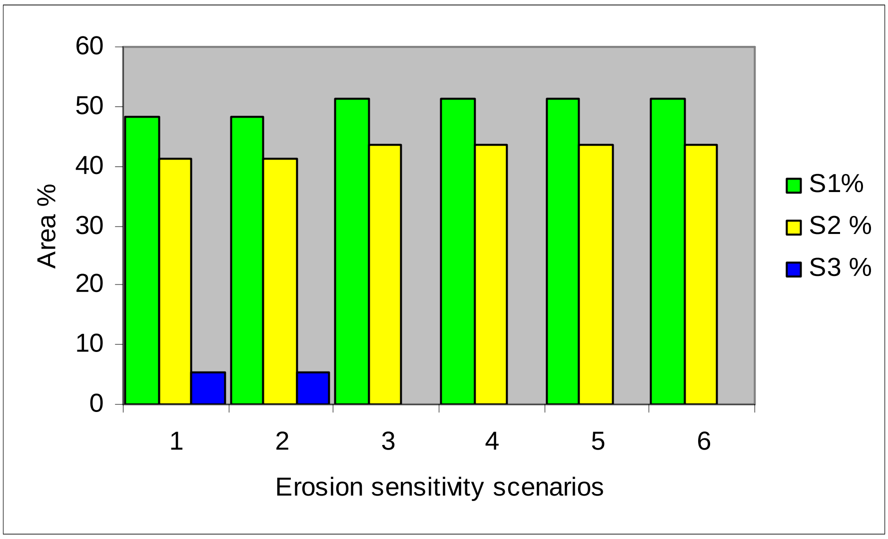


Figure 7. 35 Sensitivity analysis of Erosion for Maize

For sorghum, similar results ass for the other crops can be observed. However, sorghum shows the least variability in terms of erosion (Figure 7.34). The suitability pattern only slowly changed when threshold values decreased. Three suitability classes were observed in scenario 1 and 2. An explanation of such low changes is offered by the fact that the most of the study area at low erosion risk.

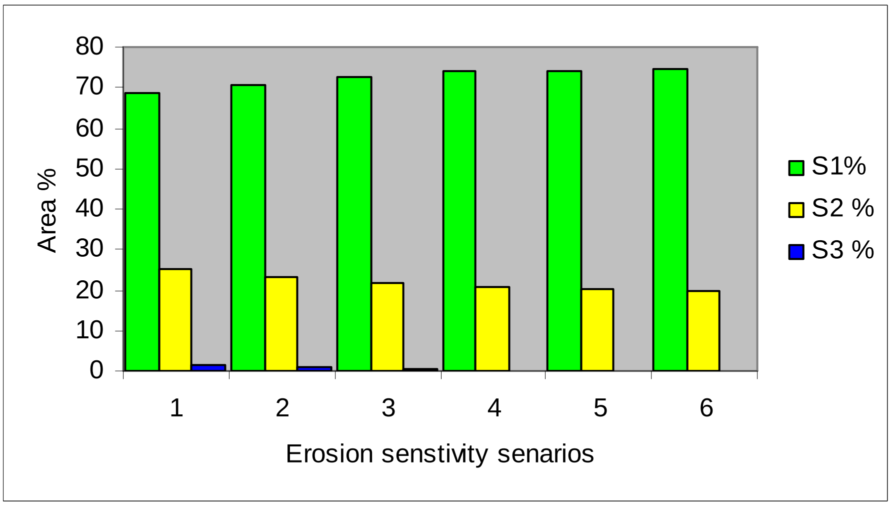


Figure 7. 36 Sensitivity analysis of Erosion for Sorghum

7-2-3-4 Sensitivity Analysis for Soil

Sensitivity analysis of the eleven land characteristics of the soil grouping was conducted. These characteristics are: rootable depth, available water holding capacity (AWHC), soil reaction (pH), organic matter (o.m.), cation exchangeable capacity (CEC), soil salinity (EC), soil alkalinity (ESP), carbonates ($CaCO_3$ %), stoniness (%), infiltration rate and hydraulic conductivity (HC).

The analysis was performed by systematically changing the threshold values of suitability classes. The output suitability classes were then compared by subsequent visual assessment and area calculations taken for each suitability class. The sensitivity analysis scenarios for each land characteristic are presented in Appendix E (E5).

The results of sensitivity analysis for the eleven land characteristics indicated that number physical and chemical characteristics are particularly sensitive in the study area. These physical characteristics include rootable depth, available water holding capacity (AWHC) and infiltration rate. The sensitive chemical characteristics were soil reaction (pH), soil salinity (EC), and exchangeable sodium percentage (ESP). In the next sections, the findings of the sensitivity analysis of soil for each crop are presented and explained.

- **Barley**

The results of the sensitivity analysis and scenarios tested of soil characteristics are presented in Appendix E5. The outputs indicated that available water holding capacity (AWHC), rootable depth, soil reaction (pH), and infiltration rate are the most highly sensitive characteristics.

For the AWHC, the sensitivity scenarios tested and results are presented in Table E5-5 and Table E5-6, Appendix E. Three suitability patterns emerged when the threshold values changed (Figure 7.35). The first pattern appeared when the threshold values decreased as described in scenario 1. In this scenario, the highly suitable class increased to 78 % (scenario 1). The second pattern emerged as a result of scenario 2 and scenario 3. Three suitability classes (S1, S2, and S3) can be observed in these scenarios. The third suitability pattern appeared in when the threshold values increased as described in scenario 4 and 5. In these two scenarios, a significant proportion of the area was revealed moderately suitable class.

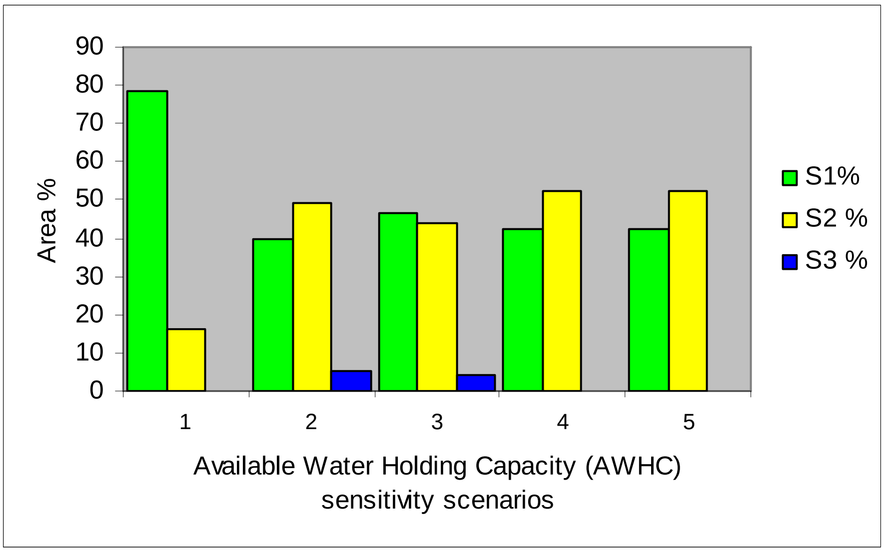


Figure 7. 37 Sensitivity analysis for Available Water Holding Capacity (AWHC) for Barley (see Table E5-5 and Table E5-6, Appendix E)

For soil depth, the scenarios tested and their results are presented in Table E5-3 and E5-4, Appendix E. There were important changes in the suitability pattern when the threshold values changed (Figure 7.36). Three suitability patterns emerged given changes in the threshold values. The first suitability pattern was as result of scenario 1 and 2. In scenario 1, the percentage of highly suitable class was 63 % compared with 46 % its proportion in scenario 3 (the default threshold value).

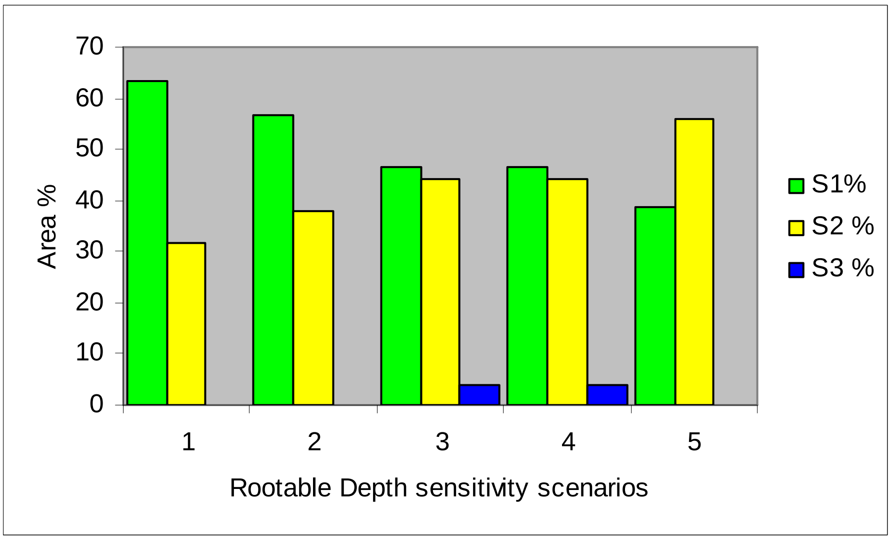


Figure 7. 38 Sensitivity analysis for Rootable depth for Barley (see Table E5-1 and Table 5-2, Appendix E)

For soil reaction, the sensitivity analysis scenarios and its corresponding outputs are presented in Table E5-2 and E5-3 respectively. The results show three suitability patterns. The first pattern appeared when threshold values of pH were increased in scenario 1 and 2. Two suitability classes (S2 and S3) can be observed in both scenarios. The second pattern emerged in scenario 3 (the default threshold value), when there were three suitability classes. The fourth suitability pattern emerged in scenarios 4 and 5. A significant proportion of the study area was revealed as highly suitable for barley. This is to be excepted because the soil reaction of most of the study area and Libyan soils in general is between a pH of 7 and 8.

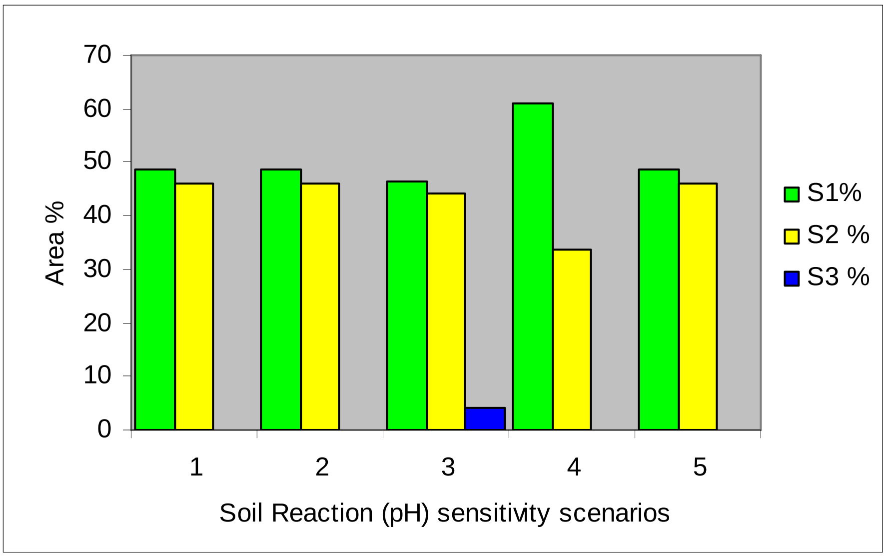


Figure 7. 39 Sensitivity analysis for soil reaction (pH) for Barley (see Table E5-3 and Table 5-4, Appendix E)

- **Wheat**

The tested scenario and full results are presented in Appendix E6 (Tables E6-1 to E6-22). In this section, two indicative examples are to be discussed. The results of sensitivity analysis of AWHC and the scenario tested are presented in Tables E6-4 and E6-5, Appendix E. The results show a change in the suitability pattern when the threshold values changed. Two suitability patterns emerged from the sensitivity analysis. Two suitability classes appeared when scenario 1 and 2 were run. Three suitability classes observed when the threshold values were increased (scenario 2 and 3).

For the soil depth, the results of the sensitivity analysis and scenario tested are presented in Table E6-1 and E6-2, Appendix E. The outputs show a change in suitability pattern with the change in threshold value. When the threshold value decreased, the proportions of S2 and S3 were comparable. While when the threshold increased a significant percentage of S2 was observed.

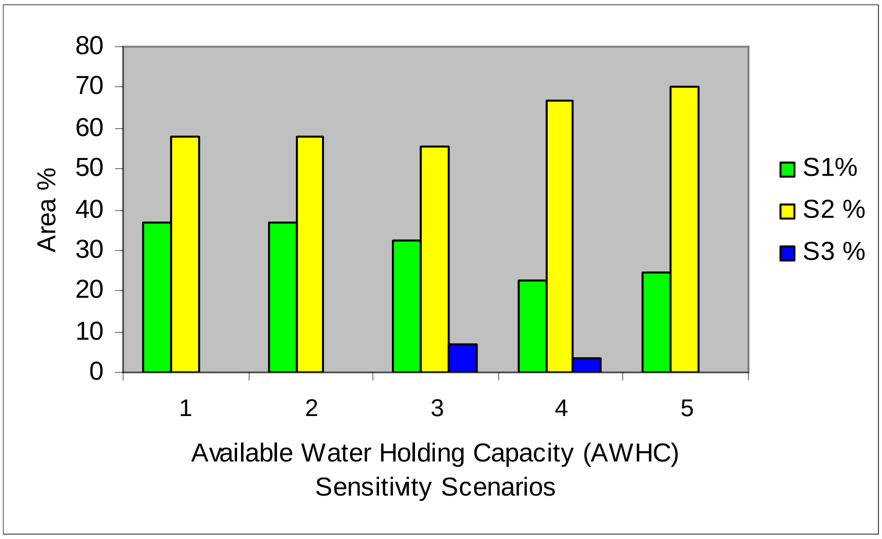


Figure 7. 40 Sensitivity analysis for Available Water Holding Capacity (AWHC) for Wheat (see Table E5-5 and Table E5-6, Appendix E)

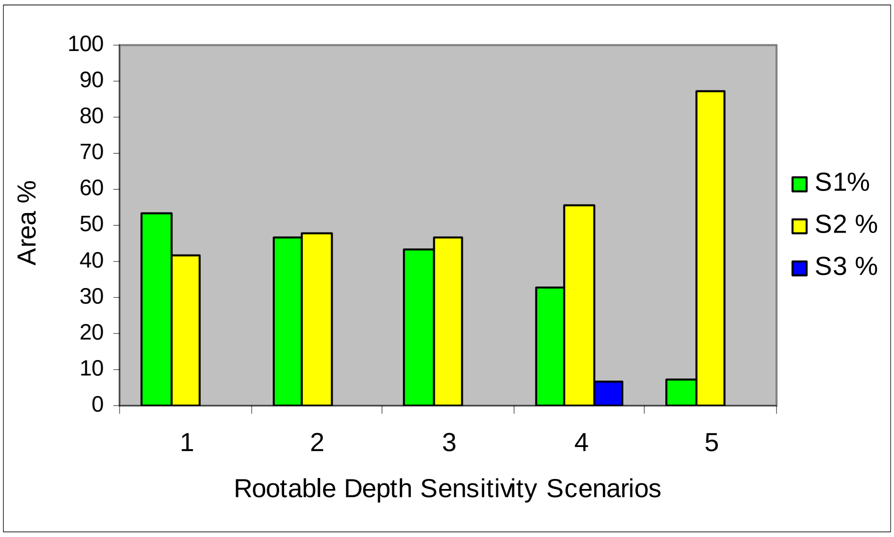


Figure 7. 41 Sensitivity analysis for Rootable depth for Wheat (see Table E6-1 and Table E6-2, Appendix E)

- **Maize**

The output of sensitivity analysis of maize revealed that number of land characteristics are highly sensitive for maize. These land characteristics are : rootable depth, soil reaction (pH), available water holding capacity (AWHC), organic matter (o.m), cation exchangeable capacity (CEC), Infiltration rate and soil salinity (EC).

The full tables, codes, and results for sensitivity analysis for all land characteristics are shown in Appendix E (E7-1 to E7-22). In this section, two indicative examples will be given for the results of the analysis. The first is sensitivity analysis for organic matter and the second is for the cation exchange capacity (CEC).

For organic matter, the results revealed that when the threshold changed there were slow changes in the overall suitability (Tables E7-9 and E7-10, Appendix E). Three suitability patterns can be observed when the changes to the threshold values were undertaken (Figure 7.41). The first pattern emerged when the threshold value was decreased (scenario 1 and 2). A significant percentage of the study area was revealed as highly suitable class. The second pattern was in scenario 3 and 4, the proportions of highly and moderately suitable class were similar. In addition, the marginally suitable class appeared. The third pattern was emerged in scenario 5. A significant proportion of the study area was revealed as moderately suitable class.

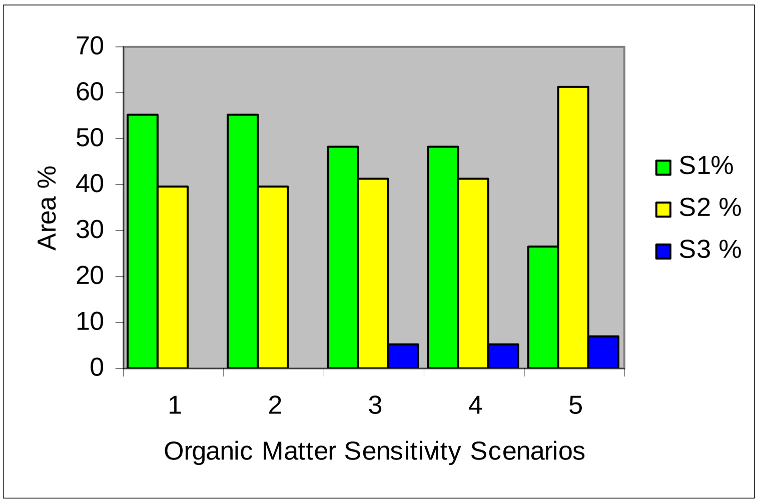


Figure 7. 42 Sensitivity analysis of Organic Matter for Maize (see Appendix E for codes for scenarios)

For CEC, the results of sensitivity analysis indicated that with changes in the threshold values of CEC, there were slow changes in the suitability patterns. (Figure 7.42). The threshold value and results are presented in Tables E7-11 and E7-12, Appendix. Five scenarios were tested and the changes in suitability pattern were slight. Three suitability patterns appeared throughout the different sensitivity scenario. Scenario 4 was the default threshold values. When the threshold values were decreased, the proportion of highly suitable increased (scenario 1). When the threshold values were increased, a significant proportion of the suitability classification resulted in the moderately suitable class. The proportion of highly suitable class was 55 % in (scenario 1) and 26 % in (scenario 5).

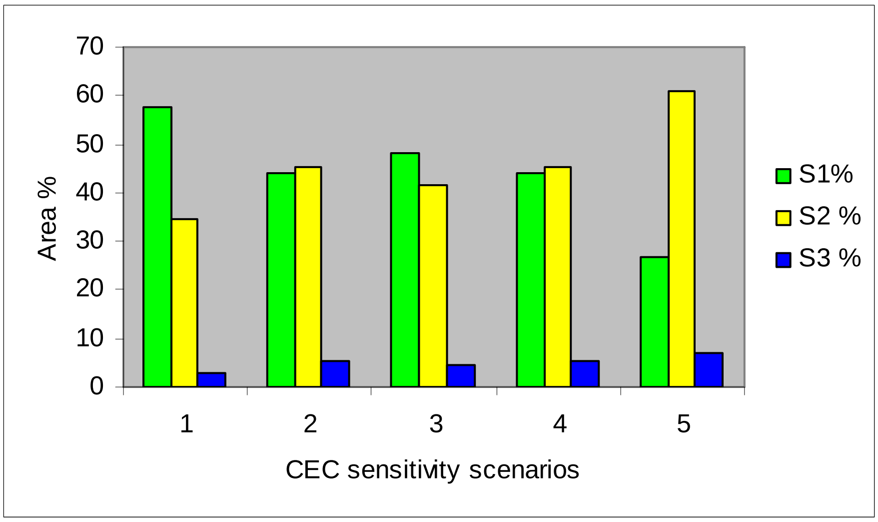


Figure 7. 43 Sensitivity analysis of Cation Exchange Capacity (CEC) for Maize (see Appendix E for codes for scenarios)

- **Sorghum**

The results of sensitivity analysis revealed that sorghum showed the least variability in suitability patterns in all crops. However, the results from weighted overlay schemes indicated that soil is the most sensitive factor in the suitability classification for sorghum. The results from the sensitivity analysis of the land characteristics revealed that physical soil characteristics are more sensitive than soil chemical characteristics.

For AWHC, the sensitivity analysis results and scenarios tested are presented in Tables E8-5 and E8-6, Appendix E. The suitability pattern slowly changed when the threshold values change (Figure 7.43). When the threshold values decreased, a significant proportion of the study area was revealed as highly suitable class. Equally, when the threshold values increased, the resulting highly suitable proportion decreased. The percentage of highly suitable class was 70 % in scenario 1 and 52 % in scenario 5.

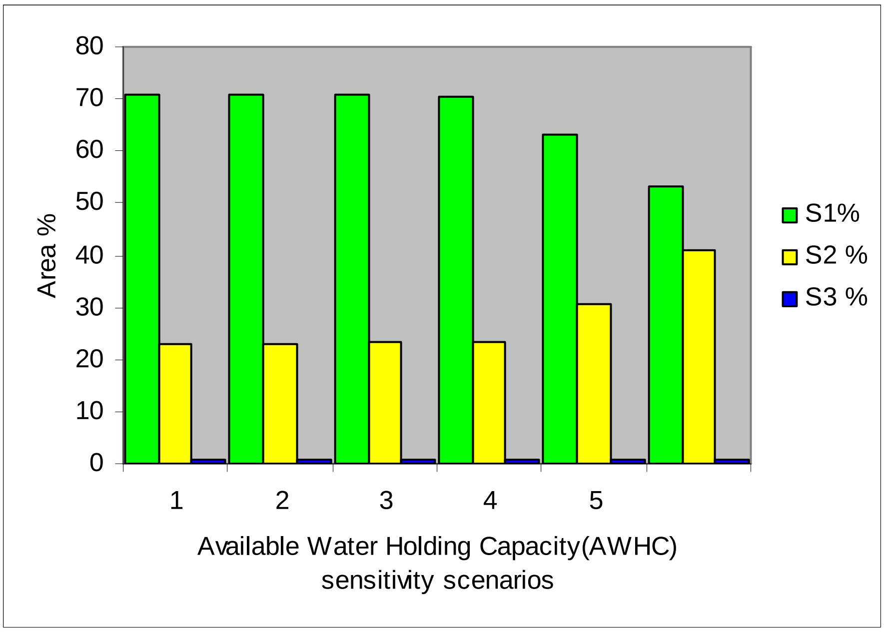


Figure 7. 44 Sensitivity analysis of Avialable Water Holding Capacity (AWHC) for Sorghum (see Table E8-5, Appendix E for codes for scenarios)

7- 3 Discussion

7-3-1 General Discussion

Sensitivity analysis offers many interesting possibilities in determining the most important parameters in the model as well as the relationship between these input parameters, and how they affect the model results. It also allows the identification of which parameters truly influence changes in the results obtained. This way the model becomes simpler and prioritisation of the acquisition of information required becomes more obvious and easier.

The sensitivity analysis conducted in this research aims to establish what the the most important factors are affecting the suitability for the selected crops within the study area. Such an approach plays a valuable role in the modelling process by helping to address the uncertainties inherent in the definition of the importance of the suitability criteria (soil, climate, slope and erosion). The analysis was accomplished by the implementation of a weighting scheme where for each factor in turn its weighting within the model was varied. At the same time, the other factors assessed retained an equal weighting. This approach allowed a focus to be made upon each factor in turn and independently. The findings of the weighting schemes emphasised that soil and climate represented the most important factors in the study area. Conversely, slope and erosion were found to be less important in the study area. The explanation for this is that most of the study area is located in Benghazi plain where there are, for topographical reasons, lower erosion risks and slope angles. The results revealed that wheat exhibits the greatest variability between classes across the range of weightings considered. Barley and maize were comparable to each other and sorghum showed the least variability. The variability observed was both on the proportion of the suitability classes and on the pattern of the variation from one class to another. When the soil weighting was increased the proportion of the lower suitability classes increased. The thresholds, or breaking points, which induced the greatest changes in the weighting scheme occurred at 55 % for the soil-related factor. The findings presented here are of great important when the model is applied, specifically in determining the appropriate weightings of each of the suitability criteria. In summary, soil should be give the highest importance, then climate, then slope and finally erosion. The sensitivity analysis was conducted for each land characteristic by changing its threshold values. The findings revealed there are a number of particularly highly sensitive characteristics which influence the results strongly. These land characteristics are: temperature, rootable depth, available water holding capacity, infiltration rate, hydraulic conductivity, soil reaction, soil salinity, cation exchange capacity, and organic matter. Temperature was sensitive for all crops. Physical soil characteristics were highly sensitive in barley and sorghum. The chemical soil characteristics were sensitive for wheat and maize. For example, soil salinity was sensitive for maize and wheat and less sensitive for barley and sorghum. This is as would be expected as sorghum and barley are both crops tolerant of high levels of soil salinity and their critical limits are higher than those for wheat and maize.

It was very important to determine the highly sensitive characteristics, which greatly affect the suitability pattern. This leads to more emphasis on the highly sensitive characteristics and therefore ultimately to more accurate suitability classifications. The sensitivity analysis showed the threshold values to mostly correct and important changes occurred if those limits increased or decreased. The model can be used in other areas to the north of Libya where similar environmental condition exist. However, in applying the models in any other areas, the weighting of the suitability criteria should be investigated i.e. the methodology is considered highly transferable, but not the weightings selected.

7- 3-2 Using Sensitivity analysis to guide crop trials

Sensitivity analysis can be used in guiding decisions as to where to locate crop trial plots. The analysis revealed that there are some sensitive geographical areas which can be taken into consideration when the location of the trial is determined.

There are five geographical areas which can be considered for the location of crop trial plots. These areas were identified by screening the outputs from the model throughout the sensitivity analysis. These areas have been observed to exhibit changing their suitability patterns thorough the analysis. In addition, these areas were discovered to be situated on different soil types. This makes them particularly appropriate sites for validating the outputs of the suitability classification. Utilising these plots will provide a good spread of data points, encompassing all the parameters contained within the model. Table 7.5 lists the proposed crop trial plots in the study area, their soil types, and suitability patterns. Figure 7.43 shows the location of the proposed trials in the soil map in the study area.

Table 7. 5 Proposed sites for crop trial plots in the study area

Site no	Trial name *	Soil Types	Suitability patterns
1	Qamins	Crusts	S2/S3
2	Benghazi	Reddish Brown Arid Soils	S1/S2/S3
3	Tukrah	Red Ferrisiallitic Soils	S1/S2/S3
4	Al Marj	Rendzinas	S1/S2
5	Abyad	Lithosols	S2/S3/ NS

(* = trial is given the name of the nearest city)

Source: (developed by the author)

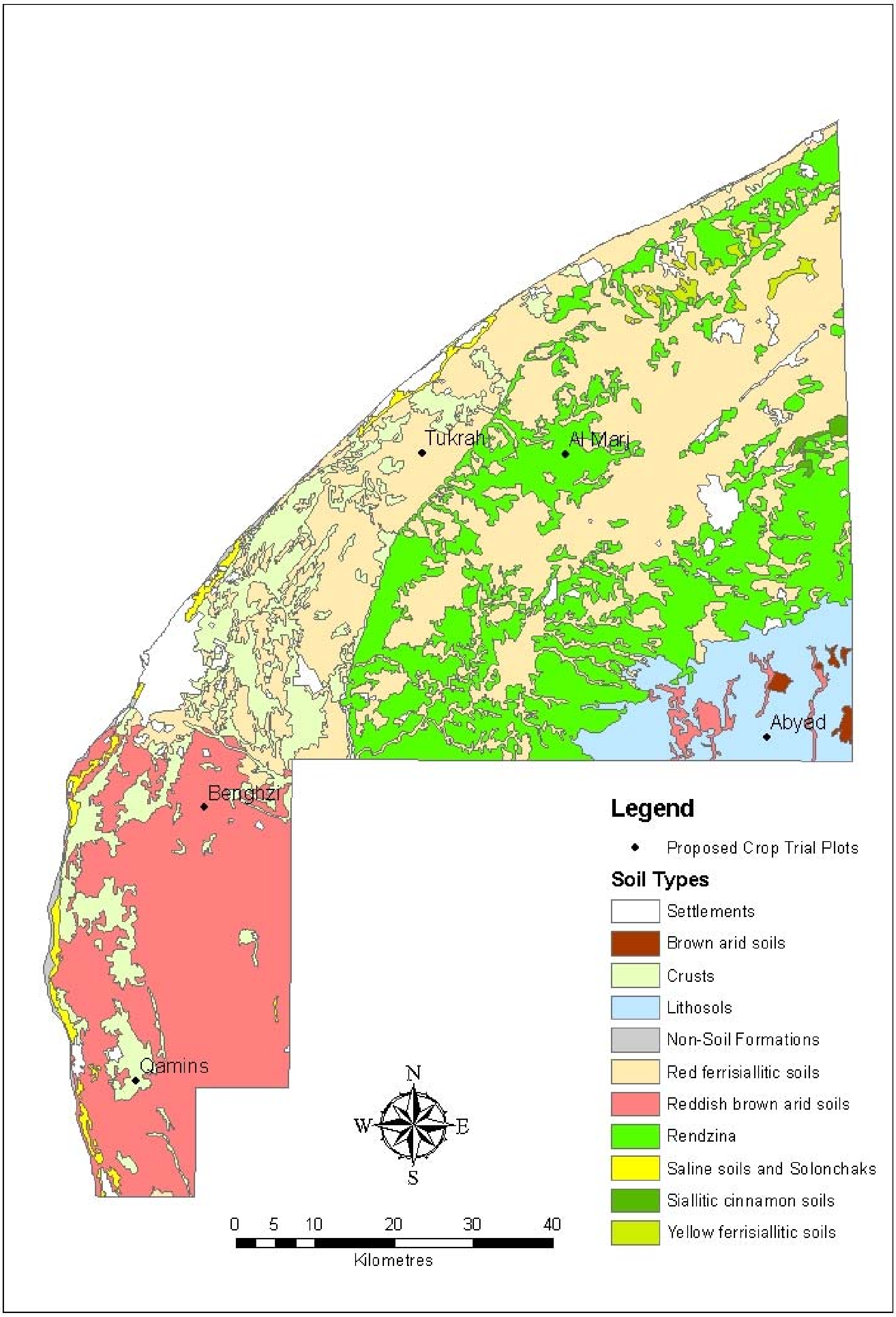


Figure 7. 45 Soil Types and proposed Crop Trials in the study area

7- 4 Conclusion

A GIS was used as a platform enabling the management of the criterion data, production of criterion layers, and calculation of attributes by the means of spatial analysis, carrying out the combining of decision criteria by the means of modelling, and conducting sensitivity analyses and production of the maps needed in land evaluation.

Three stages of testing-verification, validation, and sensitivity analysis have been undertaken in order to gain confidence in the suitability model developed in this research. The verification process involved ensuring that the model has been developed in correct manner, i.e. substantiating that the model properly implements its specifications. Many tests were undertaken to ensure that the model behaved as intended. Validation refers to building the “correct model” i.e. establishing that a model achieves an acceptable level of accuracy in its predictions. Validation was based on a subsequent qualitative comparison between the outputs of the model, local expert opinion and farmers’ judgements to ensure that the land suitability classification was in agreement with what was to be expected from the land. Although the results were largely in agreement with the expert and farmers expectations of the land, crop trials are needed in order to validate the model formally in the field. This was not possible during the period of the study. However, areas where this could be pursued were identified through the use of the model. Sensitivity analysis provided further confidence in the model and indicated the priority areas for refinement when further versions of the model could be developed. In the following chapter, conclusions based on the research results and lessons learnt from this research will be discussed and presented.

8

Conclusion

This Chapter concludes the research findings and explains its contribution.

8-1 Introduction

This research has led to the development of a land suitability model, which provides a standardised framework for the characterization of climate, soil, erosion and topographic conditions relevant to agricultural production in the north of Libya. It identifies crop-specific limitations of climate, soil, and terrain resources. It computes systematically spatial and temporal data on maximum potential.

The prototype system represents a loosely coupled system of optimisation and GIS models. The optimisation model is implemented with a set of Excel spreadsheet files. The model output is saved as tables that are brought into ArcGIS for allocation analysis. Such a system is flexible such that different objective and constraint values in the optimisation model can be used to represent different scenarios. In addition, the objective and constraint variables can be modified to reflect the different factors to be considered in any study area. The factors used in the GIS-based land allocation process also can be added to or replaced with other factors that best represent the land suitability analysis at a location. This flexible feature should make the system usable anywhere.

This research provides information relevant for decision-making. It is of particular interest to national organizations dealing with aspects of agriculture, land and water resources, food security, agricultural development, and policies notably in arid conditions. The study outputs and procedures can be beneficially applied to land use planning especially in the North East of Libya.

The land evaluation used in the study area is qualitative and no economic evaluation was conducted. This was due to the lack of economic data and there no permission was secured for this data. However, the advantage of this model is that it can be used regardless of the source of water (groundwater or desalination). In addition, the economic evaluation may become outdated in a short period of time.

The land suitability model can be improved if further data are provided. Georeferenced soil data and more meteorological data will improve the accuracy and purity of the output suitability maps.

8-2 Conclusions

The general conclusions are listed according in the objectives set out for this study in Chapter One as follows:

Objective 1

A critical assessment of the available land evaluation methodologies has resulted in the selection and development of a robust framework, suited to Libyan agricultural policy requirements. This approach is effective as it provides a synthesis of the implications and requirements of GMRP as implemented within the chosen study area (optimising resource allocation whilst taking into account social and political implications).

The development of methodological framework was achieved by reviewing range of alternative methodologies considering advantages and disadvantages of each in turn. This comparison allows the most appropriate methodology to be determined efficiently and objectively.

Objective 2

The data available to this research were assessed and reviewed, guiding the selection of the methodology. The assessment identified a number of significant limitations in the data available. This restricted the choices of suitable methodologies. Data limitations included, firstly, mapping units containing a few profile descriptions, and secondly, maps with no linked information concerning sub dominant soil types.

The development of the model criteria (LQ/LC), specifying and calibrating parameters of the framework, has taken into account all the available literature, publications and data available, as well as the opinions of key stakeholders in the Libya agricultural ministry.

This was seen to affect the certainty of the model outputs. Therefore, there is a need for specific field testing to validate the limited soils information. Field site tests are required to 'ground truth' the data used by the model, especially where capital decisions may follow.

Objective 3

The development of a land suitability model for barley, wheat, maize, and sorghum in the North East of Libya was undertaken, the land suitability assessment of the selected crops being based on the requirement for each crop.

Based upon the assessment, an environmental information system was implemented, allowing the combination of the data sets, together with the specific model framework, being capable of producing thematic interpretations (or rather mapped output relevant to agricultural policy).

The land suitability model developed for can be used by the average computer user, whilst producing outputs comparable with more complex models.

Objective 4

The compilation of validated and verified key data (fully specified within the wider model framework) was complemented by a comprehensive process of sensitivity analysis, leading to a more robust model framework and a greater sense of confidence in its output.

Model evaluation and checking was conducted through verification and validation of input data, and sensitivity analysis of output data. Verification was performed to ensure the model implemented its specifications correctly; validation ensured no issues of missing data occurred. Sensitivity analysis was conducted to address the uncertainty existing in the weighting of the suitability criteria and the threshold values of the land characteristics. The analysis was accomplished by the implementation of a weighting scheme where for each factor in turn its weighting within the model was varied. At the same time, the other factors assessed retained an equal weighting. The threshold values of each land characteristic was increased and decreased to address the uncertainty in the threshold values. This approach to the sensitivity analysis ensured that the relationships between land characteristics were explored thoroughly, and that their individual contributions to the model output were correctly characterised.

The findings of the weighting schemes emphasised that soil and climate together represented the most important factors in the study area. Conversely, slope and erosion were found to be less important in the study area.

The findings revealed a number of particularly highly sensitive characteristics which influence the results strongly. These land characteristics are: temperature, rootable depth, available water holding capacity, infiltration rate, hydraulic conductivity, soil reaction, soil salinity, cation exchange capacity, and organic matter. Temperature was seen as sensitive for all crops. Physical soil characteristics were highly sensitive for barley and sorghum. The chemical soil characteristics were sensitive for wheat and maize. Soil salinity was sensitive for maize and wheat, and less sensitive for barley and sorghum. This is as would be expected as sorghum and barley are both crops tolerant of high levels of soil salinity and their critical limits are higher than those for wheat and maize.

The sensitivity analysis was used to guide the selection of field trials sites and this was an important aspect of the research. These sites were identified by screening the outputs from the model throughout the process of sensitivity analysis. These areas have been observed to exhibit changing their suitability patterns thorough the analysis.

Objective 5

The development of a methodology and prototype framework was successfully undertaken in an area of the world where it has never done before. The land suitability assessment represents the first of its kind in Libya and offers a new prospect for land evaluation studies. The land suitability model developed in this research is the first comprehensive attempt in the Libyan context to use computerised land suitability and GIS to aid decision-making in land use planning.

The model can be further improved and developed, and a series of suggestions are proffered, for instance to enhance and improve the underlying soil and climatological data resources. Additionally, erosion plots and field trials for the selected crops could provide outputs that build upon the existing model output's accuracy.

9

Research Recommendations And Future Applications

This Chapter discusses Libyan agricultural development, the future application of land suitability assessment within Libya and outlines lessons learnt from this research

9-1 Future Aspects for Land Evaluation studies in Libya

The most important developments for land evaluation applications in Libya have been the use of knowledge-based expert systems and the associated application of Geographical Information Systems. This combination has enabled the production of specific information relevant to land evaluation studies.

While there have been previous manual attempts to achieve optimal land capabilities, these have created significant amounts of paperwork. This research, for the first time in Libya, uses a computerised land suitability model. In addition, the added geographic dimension and production of information for land evaluation is unique for Libyan agriculture.

A key element in this study was the use of a Geographic Information System. This component of the study enabled the evaluator to produce specific land information maps for each LUT. This study has shown how an evaluator could build specific regional land evaluation models incorporating local knowledge and requirements. The selection of LQ/LC and LUR to include local conditions and data into the results was an important element in establishing the regional dimension of the model. The results could be analysed and presented for any relevant use by the planners and decision-makers at whatever scale the evaluation is being undertaken.

9-2 Spatial Land Evaluation- the way forward for Libyan Agriculture

This study brings a new dimension to land evaluation, and the analysis and presentation of its results to Libyan agriculture. The limitations of conventional methods and the huge administration burden they create has been simplified and made efficient with this approach. It is not a single-step process. However, the use of the latest technology available made the study more productive and efficient for land evaluation. In addition, the model proposed is user-friendly and the average computer user can easily run it.

The use of an information system with a geographic dimension for evaluation and planning could be one way forward for Libyan agriculture since agricultural production is considered essential for regional development and sustainability as well as for food security.

The model developed in the study area could respond to swift changes in agriculture practices in Libya and so could play a vital role in agriculture. Conventional land evaluation methods are not responsive in that they only reflect the present conditions. Developing a responsive model, where the changes in crop production methods could be easily reflected in the results, supporting further spatial analysis of the changes, is the only way forward for crop suitability assessment, especially in Libya.

The model will make a great contribution in establishing trials for the selected crops. Future trials can be established in areas where the model identifies a pattern of changing suitability for the selected crops. This approach will save time and effort compared with the conventional methods.

9-3 Recommendations

This study highlights many important issues concerning land evaluation and agricultural development in Libya. These issues are related to social, political and agricultural conditions. In the light of this research, it is recommended:

- Firstly, there is a need for specific field tests to validate the soils information (known to be sparse). These, alongside field trials would form an important basis for 'ground truthing' of the model results. Thus, any capital decisions would be founded on the best possible knowledge.
- Secondly, there is an urgent need for national geographical information systems, which can accommodate tasks such as providing resource inventories. For example, this includes managing and retrieving soil or geological information, maintaining cartographic and statistical coverage, and predicting land productivity in biological and economic terms under a variety of scenarios. If this can be achieved, then land evaluation studies will be effective, accurate and responsive to the country's needs.
- Finally, funding needs to be provided and sustained for research institutions, in addition to training a labour force which will carry out this development.

10

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Appendix A

Table (A1) Population growth in Libya from 1970 to 2003

Year	Total Population	Rural Population	Urban Population	Non Agricultural Population	Agricultural Population
1970	1986	1086	900	1257	729
1971	2069	1057	1012	1335	735
1972	2156	1028	1128	1417	739
1973	2248	1000	1248	1504	744
1974	2344	976	1368	1597	747
1975	2446	957	1489	1695	751
1976	2553	945	1608	1799	754
1977	2664	939	1725	1909	755
1978	2782	937	1845	2025	756
1979	2908	936	1972	2151	757
1980	3043	934	2109	2286	757
1981	3189	929	2259	2440	748
1982	3343	924	2419	2605	738
1983	3499	917	2581	2776	723
1984	3648	910	2738	2945	703
1985	3786	903	2883	3109	677
1986	3909	895	3014	3265	644
1987	4019	888	3131	3412	606
1988	4119	879	3240	3555	564
1989	4213	871	3343	3694	519
1990	4306	861	3444	3835	471
1991	4396	851	3545	3944	452
1992	4485	840	3644	4051	434
1993	4572	829	3743	4156	416
1994	4661	819	3842	4262	399
1995	4751	809	3941	4368	383
1996	4843	801	4043	4476	368
1997	4939	793	4145	4586	353
1998	5036	787	4250	4697	339
1999	5136	781	4356	4811	326
2000	5237	774	4463	4925	313
2001	5340	768	4572	5041	300
2002	5445	763	4682	5158	287
2003	5551	759	4792	5276	275

Source: (FAOSTAT, 2004)

Table (A2) Crop production of the Wheat, Maize and Barley in Libya between 1970 and 2002

Year	Wheat Production Mt	Maize Production Mt	Barley production Mt	Irrigated Area 1000 ha
1970	240954	330	33980	175
1971	252478	504	37115	180
1972	270658	398	38734	185
1973	318351	580	39845	190
1974	390059	310	37555	195
1975	417911	1684	36654	200
1976	446527	2761	35892	205
1977	468595	1765	35590	210
1978	481111	3056	34825	215
1979	495247	3100	39516	220
1980	514818	3200	41000	225
1981	536968	3200	38500	225
1982	556658	3200	35000	227
1983	579260	3200	33500	300
1984	590477	3200	34500	300
1985	615440	3300	37333	300
1986	635221	3400	45000	300
1987	661665	3500	46500	364
1988	688672	3600	48500	364
1989	709022	3700	49500	364
1990	739664	3800	51000	470
1991	731925	3900	52000	470
1992	744896	4000	54000	470
1993	756058	4100	56900	470
1994	770198	4200	58600	470
1995	787022	4300	60900	470
1996	805659	4500	63000	470
1997	821756	4600	65000	470
1998	821269	4700	67005	470
1999	849829	4800	69148	470
2000	866468	4800	69148	470
2001	899215	4991	69148	470
2002	930306	5107	69004	470

Source: (FAOSTAT, 2004)

Table (A3) Barley Production, Area harvested and Yield in Libya between 1970 and 2004

Year	Barley Area Harvest ha	Barely Production Mt	Yield Kg /ha
1970	215892	52807	2446
1971	166666	32127	1928
1972	163949	116395	7099
1973	286287	204514	7144
1974	334068	144872	4337
1975	368422	191775	5205
1976	419400	196364	4682
1977	181273	59204	3266
1978	418000	196476	4700
1979	340000	100000	2941
1980	280250	71000	2533
1981	231500	120620	5210
1982	134500	99600	7405
1983	300000	203000	6767
1984	214000	87000	4065
1985	190000	80000	4211
1986	200000	90000	4500
1987	249518	99700	3996
1988	232893	119000	5110
1989	252035	134048	5319
1990	296742	141476	4768
1991	260000	125000	4808
1992	185000	90000	4865
1993	105000	50000	4762
1994	85000	40000	4706
1995	50000	23000	4600
1996	59000	28200	4780
1997	85000	42100	4953
1998	135000	65000	4815
1999	155000	75000	4839
2000	170000	80000	4706
2001	170000	80000	4706
2002	170000	80000	4706
2003	170000	80000	4706
2004	170000	80000	4706

Source: (FAOSTAT, 2004)

Table (A4) Wheat Production, Area harvested and Yield in Libya between 1970 and 2004

Year	Wheat Area Harvest ha	Wheat Production Mt	Yield hg/ha
1970	156735	27189	1735
1971	53490	17726	3314
1972	109737	41585	3790
1973	148949	67327	4520
1974	132681	38682	2915
1975	200500	75134	3747
1976	296600	133101	4488
1977	201839	48117	2384
1978	266180	99295	3730
1979	264000	110000	4167
1980	272000	140500	5165
1981	215700	123110	5707
1982	242000	188000	7769
1983	248000	209737	8457
1984	257000	183634	7145
1985	200000	149000	7450
1986	220000	190000	8636
1987	191491	172000	8982
1988	193093	161011	8339
1989	228482	185000	8097
1990	104538	128760	12317
1991	105000	130000	12381
1992	105000	125000	11905
1993	150000	126000	8400
1994	155000	120000	7742
1995	160000	117000	7313
1996	170000	124000	7294
1997	155000	156400	10090
1998	160000	140000	8750
1999	165000	130000	7879
2000	165000	125000	7576
2001	165000	130000	7879
2002	165000	125000	7576
2003	165000	125000	7576
2004	165000	125000	7576

Source: (FAOSTAT, 2004)

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Table (A5) Maize Production, Area harvested and Yield in Libya between 1970 and 2004

Year	Maize Area Harvest ha	Maize Production Mt	Yield hg/ha
1970	1210	1262	10430
1971	690	829	12014
1972	1068	1329	12444
1973	808	1208	14950
1974	734	1206	16431
1975	983	1175	11953
1976	1036	1144	11042
1977	1028	1111	10807
1978	1052	1150	10932
1979	1010	1086	10752
1980	980	931	9500
1981	980	1000	10204
1982	980	1000	10204
1983	980	1000	10204
1984	980	1000	10204
1985	900	920	10222
1986	800	850	10625
1987	750	770	10267
1988	600	620	10333
1989	500	530	10600
1990	400	400	10000
1991	400	400	10000
1992	400	400	10000
1993	400	400	10000
1994	400	400	10000
1995	400	400	10000
1996	380	400	10526
1997	400	700	17500
1998	500	900	18000
1999	600	1200	20000
2000	2000	5780	28900
2001	1000	2000	20000
2002	1000	1500	15000
2003	1000	2000	20000
2004	1000	2000	20000

Source: (FAOSTAT, 2004)

Appendix B

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Table (B1.1) Soil Sub-types in the Eastern Zone in Libya according to

code	Soil sub-types
Ad	Alluvial differentiated soils
Bd	Brown arid differentiated soils
Bsd	Brown arid slightly differentiated soils
Code	Soil subtypes
CRm	Monolithic crusts
CRnm	Non - monolithic crusts
CScp	Siallitic cinnamon compact soils
CSt	Siallitic cinnamon typical soils
Dt	Dark compact typical soils
FBd	Reddish brown arid differentiated soils
FBdcr	Reddish brown arid differentiated crust soils
FBhcr	Reddish brown arid hydromorphic crust soils
FBnd	Reddish brown arid non - differentiated soils
FBsd	Reddish brown arid slightly differentiated soils
FBsdcr	Reddish brown slightly differentiated crust soils
Fc	Red ferrisiallitic concretionary soils
Fcr	Red ferrisiallitic crust soils
Fh	Red ferrisiallitic hydromorphic soils
Fhd	Red ferrisiallitic hydrated soils
Fi	Red ferrisiallitic soils of a truncated profile
Ft	Red ferrisiallitic typical soils
Lb	Brown lithosoils
Lcs	Cinnamonic lithosoils
Ltb	Reddish brown lithosoils
RZ	Dark rendzinas
RZr	Red rendzinas
Sa	Automorphic solonchaks
Sh	Hydromorphic solonchaks
SHcr	Hydromorphic crust solonchaks
SHs	Hydromorphic sebkha solonchaks
SM	Maritime sands
Yc	Yellow ferrisiallitic concretionary soils
Yt	Yellow ferrisiallitic typical soils

B(1.2) A brief description for the Soil Sub-types in the study area

1- Brown arid soils

The total area of the brown arid soils approximates 1% of the study area. The formation of brown arid soils takes place under conditions of arid and extra-arid types of bio- climate, which is characterised by the alternation of a short (3-4 months) moistening period and a long (8-9 months) drying period. Mean annual temperature of these soils is about 20 C. The hottest month is August and the coolest is January. Annual precipitations are 50 – 150 mm.

The brown arid soils developed on eluvial- deluvial and eluvial-proluvial carbonate, often saline, deposits of loamy and less frequently clay texture. Bedrock is represented by Oligocene and Miocene limestones f; 1984; Suliman, 1989; Mahmoud, 1995).

The genesis of the brown arid soils is determined by the predominance of the desert soil formation. The main soil formation process is often superimposed by the process of salinisation, agrillisation, and alkalinisation.

During the wet period, the processes of intra soil weathering are most intensive; the process of agrillisation of the middle part of the profile is also take place (Mahmoud, 1995). Developing under conditions of non-leaching water regime leads to a weak degree of leaching from carbonate and readily soluble salts in the brown arid soils.

The morphological feature of the brown arid soils can be summarised into: brown, light brown colour; layered structure of the upper horizon; low humus content.

2- Crusts

This soil type is a characteristics component of the soil mantel of the littoral plain in the north east of Libya. These soils are characterised by the compact plate-like carbonate Siallitic or gypsic crust horizons present on the surface or within 30 cm. The occurrence of the crusts is confined to the areas of limestones.

3- Lithosols

The geographic distribution of this soil is mainly limited to the southern macro-slope of the Jabal Akhdar Upland. These soils develop under different climatic conditions, i.e. from sub-humid to arid types of bio climate (Jindeel, 1978). The Lithosols develop mainly on alluvial-deluvial and eluvial deposits of limestones. The feature of the Lithosols parent materials is their high calcareousness. A high rate of stoniness and frequent rock outcrops are some of the Lithosol peculiar features (GEFLI, 1975).

Selkhozpromexport (1980) classified these soils into three main soil sub-types: cinnamonic Lithosol (Lcs), reddish brown Lithosol (Ltb) and brown Lithosol (Lb). As for the geographic distribution of these sub-types, the most northern area occupied by the cinnamonic Lithosols, south of which located the reddish brown and brown subtypes of Lithosols.

4- Non-Soil Formation

It occupies 1 % of the study area. The genesis of this soil is distinguished by very weak evidence of biological process of rock transformation as well as by preponderance of physical weathering. The main non-soil formation in the study area is maritime sands (SM). The thickness of these formation is varies from 0.3 m to several metres.

5- Reddish brown arid soils

The reddish brown arid soil type is the most frequent occurrence in the study area. These soils have developed in different types of landform whose morphology is characterised by a general surface flatness. The main parent materials of the reddish brown arid soils are alluvial-proluvial and proluvial Pleistocene deposits. Those deposits are predominant by layered quartz sands and loamy sands enriched in carbonates. In the coast strip of littoral plaina considerable area is occupied by calcified sands containing more that 40 % of calcium carbonates (Selkhozpromexport, 1980; Mahmoud, 1995).

The reddish brown arid soil type in the study area divided into the following sub-types

1- Reddish brown arid differentiated soils (FBd)

2-Reddish brown arid differentiated crust soils (FBdcr)

3- Reddish brown arid hydromorphic crust soils (FBhcr)

4-Reddish brown arid non - differentiated soils (FBnd)

5-Reddish brown arid slightly differentiated soils (FBsd)

6-Reddish brown slightly differentiated crust soils (FBsdcr).

6- Red ferrisiallitic soils

Red ferrisiallitic occupy 36 % of the study area and these soils develop in the sub-humid and partly semi-arid sub-tropical climate. They develop in littoral abrasion-accumulative plain, the lower and upper plateaux of the Jabal Akhdar Upland. The parent material is composed of eluvial, deluvial, alluvial, alluvial-proluvial, and deluvial-proluvial limestone deposits. The parent material are characterised by red colouring due to increased content of iron oxides, clay and clay loam texture, carbonation and presence of considerable amounts of water-soluble salts on certain sites. The bedrock represented by limestones dolomitic in varying degree.

Red ferrisiallitic soils develop under variable water and thermal conditions with ferrisillitisation being the chief process. In the wet period intensive weathering take place under the conditions of the neutral and alkaline reaction which leads to decarbonation of soil profile, formation of secondary minerals high in silica, liberation of iron oxides. In dry periods due to intensive moisture evaporation there is a clear upward movement of alkali-earth bases, rubefaction of iron compounds take place.

The type of red ferrisiallitic soils is subdivided into subtypes of typical (Ft), crust (Fcr), concretionary (Fc), hydrated (Fhd), and hydromorphic soils and those with a truncated profile (Fi) (Selkhozpromexport, 1980).

7- Rendzina

The rendzina is found only in the east of Libya and they occupy 21.3 % of the study area. There are two subtypes of the rendzina in the study area: dark rendzina (RZ) and red rendzina (RZr). The geographical distribution of rendzina is limited to Jabal Akhdar upland around Al Marj region (Selkhozpromexport, 1980).

The parent materials are represented by eluvial and deluvial-eluvial deposits of calcareous rocks. These deposits are thin, mainly clay loamy and clayey , contains various amounts of rock fragments. The bedrocks are mainly represented by chalk-like hard limestones. The presence of clay in calcareous rocks composition of clay minerals may exert a rather considerable influence upon properties of the rendzina (Mahmoud, 1995).

8- Saline soils and solonchaks

Saline soils and Solonchaks constitute 1 % of the study area. The most intensive process of salt accumulation and formation of saline soils and solonchaks are observed within the close depressions of the coastal plain. The basic salts involved in the salinisation of soils of the study area are NaCl and Na_2So_4 with $CaCl_2$, $MgCl_2$, $NaHCO_3$, $MgSO_4$ and$NaCO_3$.

Mahmoud (1995) explained that three main source of the salt may be distinguished. Firstly, marine .i.e., the penetration of seawater and accumulation of its salts in the soil and subsoil, secondly, continental, which is conditioned by the groundwater lying close to the surface and thirdly, eolian slat accumulation.i.e., enrichment of soil and rocks with toxic salts of marine or continental origin through their transfer of air masses.

This type of saline soils and solonchaks is subdivided into the following sub-types: automorphic (Sa), hydromorphic (Sh), hydromorphic crust (SHcr) and hydromorphic sebkha (SHs).

9- Sialliatic cinnamon soils

This soil is common in Jabal Akhdar upland, lying in the upper plateau where they are developed under various conditions. The main parent materials of the soil are alluvial, alluvial-proluvial and eluvial-deluvial deposits. These parent materials are the product of weathering of the sedimentary, predominantly calcareous rocks. Morphologically, these soils are characterised by following feature: distinct differentiation of the profile into genetic horizons with the sequence of A, B, C or A, B, R.

The Siallitic cinnamon soils type is divided into two sub types: typical (CSt) and compact soils (CScp).

10-Yellow ferrisiallitic soils

The yellow ferrisiallitic soils are spread on the study area and constitute 1 % of the study area. They are found in Jabal Akhdar Upland lower step with a sub-humid climate which is characterised by an alternation of dry and wet seasons.

These soils generally have a small thickness and clay texture. The yellow ferrisiallitic soils develop under the predominant influence of ferrisillitisation which is characterised by the formation of, mainly, secondary alumino-and ferrisilicates (Kaolinite and illites) and accumulation of mostly hydrated iron oxides in the weathering products, the content of silicon and aluminum oxides being relatively high. The bedrock represented by firm limestones and the following sequence of genetic horizons is typical of thick profile: A1(or Ap and A1), B_1 hox, B_2 hox, B_3 hox, BC, C.

Two sub-types can be distinguished within the type of the yellow ferrisiallitic soils: typical (Yt) and concretionary (Yc).

Table (B2) Soil Chemical and Physical properties for Soil Sub-types in the Eastern Zone

Code	Soil Depth cm	AWHC mm/m	pH	EC	ESP	$CaCo_3$ %	Stones %	Hydro	Infil	CEC	O.M	B.D
Ad	53	155	5	0.19	22	5.3	5	426	4	16.1	3.3	1.76
Bd	159.67	147	5.5	0.93	9.49	30.5	2.5	72	1.2	13.33	1	1.27
Bsd	66	176	6.5	0.15	1.94	15.1	5.3	230.4	5.7	15.3	1.04	1.32
CRm	25	142	6.5	0.76	2.26	23	25.5	110.8	1.8	15.45	1.05	1.42
CRnm	27.33	186	8.6	0.46	2.3	15.9	13.5	109	1.5	15.95	1.67	1.34
CScp	137	164	8.1	0.18	0.35	27.8	0	736.2	17.4	23.15	1.91	1.25
CSt	104	174.6	7.8	0.14	0.27	16.9	7.33	770.4	15.6	22.56	3.29	1.19
Dt	300	199	8.2	0.15	0.84	31.4	0.35	172.8	7.5	26.35	1.81	1.21
FBd	181.33	186	8.3	0.14	1.5	6.6	0.2		5.94	17.87	1.14	1.23
FBdcr	74.33	154	8.3	1.53	6.77	0	0	129.6	4.2	11.31	1.04	1.22
FBhcr	98.5	173	8.7	0.59	1.95	27.5	0	230.4	0.6	13.82	1.09	1.34
FBnd	212.5	84.5	8.8	0.14	2.73	89.65	0	763.2	16.2	3.14	0.32	1.5
FBsd	133.5	126.5	8.6	0.23	1.74	31.85	0.75	504	10.2	10.89	1.07	1.45
FBsdcr	50.67	136	8.2	0.35	2.32	21.25	0	216	6.6	14.78	1.23	1.43
Fc	109.5	160	7.7	0.15	1.14	0.15	3.6	316	1.8	21.48	1.56	1.24
Fcr	81.25	188	8.4	0.18	2.05	1.45	3.05	212.4	3	17.13	1.06	1.27
Fh	230	187	7.9	0.95	18	0.725	0	230	1.5	15.9	1.53	1.37
Fhd	257.5	150	7.6	0.21	1.26	0.575	1.6		4.2	20.34	1.26	1.26
Fi	22.5	156	7.9	0.1	1.67	0.125	1.05	360	12	24.23	1.2	1.25
Ft	220	155.2	8.1	0.16	2.83	2.65	0.5		12	21.19	1.22	1.22
Lb	17.67	163	8.4	0.65	4.66	35.9	25.6	43.2	0.78	15.39	1.34	1.4
Lcs	26.5	116	8.2	0.23	1.93	15.325	24	172.8	6.5	21.14	2.8	1.5
Ltb	21.33	145	8.5	0.38	3.97	11.5	31.7	106.8	6	15.11	1.02	1.58
Rz	37.25	140.7	8.1	0.22	1.13	20.9	10.6	722.4	12	22.32	3.9	1.23
Rzr	22.5	206.5	7.9	0.36	1.75	4.3	6.9	271.32	12	22	3.26	1.22
Sa	25.75	134	7.9	3.76	2.32	23	25.8	158.4	3.6	21.7	1.16	1.37
Sh	215	355	7.9	8.96	52.25	23	0	216	6.6	11.9	2.25	1.04
Shcr	71	102	8.7	9.73	31.29	23.	0	331.2	9	16.2	1.79	1.4
Shs	140	253	8.3	30	30.2	50.	0	381	7.2	6.5	1.41	1.3
SM	115	0	8.3	0.95	4.51	89	0			2.63	0	0
Yc	300	168	7.6	0.17	2.13	15.4	2.6	230.4	0.6	21.5	0.98	1.18
Yt	182.5	177.5	7.6	0.16	0.3	0.2	9.95	417.6	6	10.6	2.04	1.32

Table (B3) Soil Texture for the soil sub-types in the study area

Soil subtypes	Sand %	Clay %	Silt %	Texture
Ad	13.4	59.1	27.5	clay
Bd	21.1	41.4	37.5	clay
Bsd	34.3	26.4	39.3	loam
CRm	42.8	41.8	15.4	clay
CRnm	46.1	26.8	27.1	sandy clay loam
CScp	21	54.7	24.3	clay
CSt	28.5	42	29.5	clay
Dt	18.6	58.6	22.8	clay
FBd	29.5	29.5	41	clay loam
FBdcr	34	36	30	clay loam
FBhcr	24.3	29.2	46.5	clay loam
FBnd	98.9	0.8	0.3	sand
FBsd	63.3	14.9	21.8	sandy loam
FBsdcr	42.5	30.9	26.6	clay loam
Fc	28.9	40.3	30.8	clay
Fcr	32.3	37.2	30.5	clay loam
Fh	16.6	53.7	29.7	clay
Fhd	18.8	54.8	26.4	clay
Fi	23.2	36.9	39.9	clay loam
Ft	20	51.1	28.9	clay
Lb	49.5	20.5	30	loam
Lcs	28.2	24	47.8	loam
Lfb	37.4	23.5	39.1	loam
RZ	32.4	33.3	34.3	clay loam
RZr	26.4	49.6	24	clay
Sa	36.5	22.9	40.6	loam
Sh	45.6	22.5	31.9	loam
Shcr	38.2	27.9	33.9	clay loam
Shs	78.8	3.9	17.3	loamy sand
SM	98.9	0.5	0.6	sand
Yc	16.3	68.6	15.1	clay
Yt	30.7	38.2	31.1	clay loam

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Table (B4) Mean monthly temperature of Benina station, Benghazi for the period from 1973 - 2002

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1973	12.4	13.4	15.2	18.2	23.7	27.0	27.5	26.2	25.8	23.0	16.7	14.6
1974	12.6	13.4	16.1	20.0	22.5	27.0	25.8	26.5	25.8	24.5	17.0	14.1
1975	11.4	12.5	16.1	19.1	22.7	24.1	24.9	25.7	25.1	21.6	18.3	14.3
1976	12.0	12.0	14.4	18.8	22.5	25.2	25.9	26.2	25.4	22.3	17.4	14.8
1977	13.7	16.2	16.3	18.0	25.3	26.4	28.2	27.6	25.0	20.6	18.3	13.4
1978	12.7	14.9	15.0	19.4	24.4	26.5	25.2	25.3	23.8	21.2	15.7	14.8
1979	12.8	15.0	17.2	18.8	21.1	26.4	26.4	27.2	25.7	24.6	17.4	14.1
1980	12.5	12.3	16.0	17.9	21.8	26.2	25.8	26.2	24.3	23.5	20.0	13.6
1981	10.3	11.9	17.3	21.3	22.1	27.5	26.9	27.5	25.6	23.7	16.4	15.2
1982	14.1	12.2	13.9	19.5	21.5	25.8	27.4	28.5	26.3	25.5	17.0	13.8
1983	11.9	12.9	15.0	20.3	22.7	25.0	26.7	26.9	25.0	21.5	18.8	13.2
1984	12.2	13.0	14.8	16.8	25.4	23.4	24.6	26.5	25.1	24.0	18.4	14.8
1985	13.6	13.5	15.7	19.5	23.6	25.7	25.6	25.9	24.5	20.8	18.8	15.3
1986	13.2	14.5	15.8	19.8	20.1	25.3	26.7	26.4	25.3	21.5	16.7	13.3
1987	12.9	14.3	12.6		20.8	24.7	26.7	27.0	25.7	23.3	18.3	15.6
1988	13.7	12.9	14.5	20.1	25.8	28.7	28.1	27.6	25.8	21.6	17.4	13.4
1989	11.7	12.7	15.5	21.4	23.0	25.6	26.0	26.1	26.7	20.4	18.0	15.4
1990	12.9	13.0	15.4	19.7	22.4	26.1	25.5	25.6	25.0	23.8	19.7	14.5
1991	12.8	12.5	16.5	18.0	21.1	25.1	25.1	25.6	25.6	24.8	17.5	12.0
1992	11.4	11.4	13.7	17.6	21.0	25.7	25.4	25.7	24.1	26.0	18.7	14.0
1993	12.4	11.2	14.2	19.1	21.6	26.6	25.6	26.0	25.9	24.4	19.9	15.0
1994	13.9	13.7	15.5	19.6	22.6	23.7	25.8	27.4	26.0	23.2	17.7	13.5
1995	11.7	13.9	15.1	17.5	21.2	29.1	26.8	28.0	28.0	21.4	15.9	14.9
1996	13.3	13.3	14.4	17.0	23.2	25.2	25.5	26.9	27.9	21.1	17.4	14.9
1997	13.2	12.5	13.0	15.6	22.5	27.9	27.4	25.9	24.8	21.7	18.8	15.1
1998	13.4	13.9	13.1	21.5	23.0	24.7	26.8	28.3	26.3	23.4	18.0	13.1
1999	13.1	12.9	16.3	19.0	24.5	27.6	25.8	28.4	27.1	24.4	19.7	15.4
2000	12.0	12.6	15.3	20.0	23.8	24.3	26.6	26.5	26.4	22.9	20.5	15.9
2001	14.5	12.9	17.7	19.3	24.2	24.3	26.9	27.3	28.2	22.9	18.8	14.0
2002	12.2	14.3	16.8	18.5	23.2	23.9	29.2	28.2	26.6	22.2	18.8	15.0

Table (B5) Monthly rainfall (mm) in Benina station, Benghazi for the period from 1973 - 2002

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1973	37.6	42.4	33.7	4.2	0	0	0	0	0.8	34	44.7	19.1
1974	59.8	42.8	33	0	0.5	0	0	0	0	21.5	53.4	136.8
1975	78.9	33.2	4.8	16	0.5	0	0	0	0	8.8	6.1	41.8
1976	81.3	40.5	21.3	5.3	16.7	0	0	0	0	28.3	33.1	24
1977	12	11.2	1.6	47.5	0	0	0	0	18.1	0	32.4	176.7
1978	92.9	105.1	75.6	4.7	0.3	0.2	0	0	5.9	109.1	21.8	49.2
1979	52.9	22.1	11.5	7.5	0.5	0	0	0	0.8	3.9	141.8	53.7
1980	37.7	33	5	11.5	0.2	0	0	0	0	8.2	0.6	61.6
1981	176.6	97	2.1	0.3	1	0	0	0	0.4	10	126.1	19.2
1982	20.8	53.4	49.9	9.1	0	0	0	0	0	3.4	54.4	97.9
1983	57.2	26.8	22.7	1.3	0.3	0.1	0	0	1.1	53.4	55.2	86
1984	59.4	57	24.3	2.9	0.4	0	0	0	0	3.3	29.6	59.8
1985	72.6	23	1.7	0.7	1.7	0	0	0	0.4	18.4	27.3	80.6
1986	36.2	17.1	43.8	0	11.3	0	0	0	6.4	27.7	13.3	116.5
1987	24.5	27	60.5		0	0	0	0	5	5.6	60.9	17.6
1988	39.1	35.7	48.9	0	0	0	0	0	11.5	8.7	8.6	160.9
1989	62.7	28.6	112.5	0	0.1	0	0	0	0	19.1	19.9	22.5
1990	61.6	27.4	0	4	9	0	0	0.1	0	0	64.1	13.5
1991	63.3	57.6	17.3	12.6	9.7	0.3	0	6.4	0	1	57.7	234.7
1992	29.6	64.1	12.5	6.3	3.2	0	0	0	0	0	59.2	30.8
1993	71	76.1	26.4	0	3	0	0	0	0.2	0	22.4	26.3
1994	117.6	35	1.9	25.4	6	0	0	0	0	42.7	61.4	72.3
1995	107.1	55.3	13.6	6.7	1	0	0	0	3.4	51.7	40.6	47.3
1996	49	76.6	24.2	4.7	0.1	0.1	0	0	3.6	21.9	21.5	57.5
1997	49.1	35.7	32.9	17.1	1	0	0	0	0.3	24.6	39.7	67.5
1998	61.3	18.4	86.4	2.8	1.8	0	0	0	0.1	20.2	35.2	77.9
1999	56	11.9	39.8	2.8	1.8	0	0	0	11.2	9.5	22.3	21
2000	73.9	31.2	0	7.1	0.6	0	0	0	5.6	4.4	20.1	55.1
2001	46.9	90.8	2	1.2	2.1	0	0	0	0	7.2	40.5	70.8
2002	43.5	44.7	33.1	3.6	0	0	0	0	11.7	35.9	30.5	75.5

Appendix C

C1- Notes from Libya visit 2002

The aims of visiting Libya were to meet some of the authorities responsible for the areas touched on by the research and meet soil experts, to have their guidance in designing the model.

Four meetings were arranged and many things topics were have been covered in these meetings.

The meeting were in order

1. Dr Khaled Ben Mahmod (the head of the Libyan Natural Resource project)
2. Dr. Ezzeddin Alteeb Rhoma (Soil expert in the Faculty of Agriculture, Alfateh University Tripoli)
3. Eng Abudlhamed Al Shake (The Director of Great Man Made River (GMMR) , Tripoli office)
4. Mr Khaled Alfathle (The head of the Department of the Geography and Climate the Secretary of Transportation)

The four meetings went very well and they were very promising

C1-1 Notes from the meeting with Dr Khaled Ben Mahmod

Dr Khaled Ben Mahmod is the member staff in the Al-Fateh University, Faculty of Agriculture, Soil and water Dept. Dr Khaled has shown interest in the research findings and the application of these findings in future land evaluation studies. He expressed his willingness to give every possible help to this research. It was felt that Dr Khaled will be one of the important contacts points of this research. There were discussions about the possibility of output model in the future land evaluation.

C1-2 Notes from the meeting with Dr Ezzeddin Rhoma

Dr Ezzeddin is a soil expert in Libyan soils and he worked in the Libyan soils area since 1978 when he came back from U.S .A (University of Oklahoma).

The meeting concerned about two main questions: what are the main factors to be taken into account when a Libyan model of land evaluation is designed and, what crops should be the grown in the eastern area of Libya.

Dr Ezzeddin outlined some important factors to be taken in account when the model of land evaluation to be designed. He stated that there are ten factors should be taken into account when land evaluation takes place and these factors are:

1. Rootable depth
2. Drainage (Soil drainage conditions)
3. Soil Salinity
4. Sodium (ESP)
5. Soil reaction (pH)
6. Calcium Carbonate percentage (CaCo3%)
7. Erosion Hazard
8. Topography (slope)

According to Dr Ezzeddin the crops which to be looked in the North-eastern region of the country are barley, wheat, maize and sorghum

C1-3 Notes from the meeting with Mr Abudlhamed Al Shake

Abudlhamed Al Sake is the Director of the Great Manmade River (GMMR), Tripoli's office. The meeting went very well. Abudlhamed has offered every possible help to this project. The data and information which are needed to this project are on the Benghazi office. Abudlhamed has offered his help to contact and arrange a meeting with Dr Ali Algabe who is the head of Benghazi office of the GMMR. Abudlhamed contacted Dr Algabe and he was not in Libya from 2nd of September until 6th of October 2002. However, Mr Al Shake has offered to help with any data or information are needed to this research. In general the meeting was successfully held and the outputs of the meeting were promising.

Mr Al Sake stated that they just started to put some documents in a digital format and consequently there aren't currently many documents to give in a digital format. However, a CD of the path of the water from the desert was provided.

C1- 4 Notes from the meeting with Mr Khaled Alfathle

Mr Alfathle is the head of the geography and climate Department in the Transportation Secretary. This department is responsible for managing the climate data.

Mr Alfathle stated that some of the data are in a digital format but the majority still in a paper format. Mr Alfathle has offered every possible help to the research. The names of the stations which are needed are supplied to Mr Alfathle and he promised to send them as soon as possible.

C1- 5 Conclusion

It was felt that the meetings were successfully held and a good connection with the keys of the research has been built. The meeting with Dr Ben Mahmod were very useful for this research. A promise has been made by Dr Ben Mahmod to give every possible help with data and information concern this project. The project (Libya 001) is a project of establishing a database for the Libyan Natural Resources.

Dr Ben Mahmod has requested a copy of the literature review of this research to consider using the output of this review as base to select the suitable land evaluation technique for the rest of the country.

Climatic data will be provided possibly in a digital format but not for all the station are required.

The meeting with Mr Al Shake was a very good start to contract The Great Man-Made River authority GMMR. The outputs of the meeting were: the area aimed to use with water transported and the path of the water within the country in a digital format.

C2- Notes from Libya visit 2003

The mission to Libya aims to give a brief for the authorities and sponsors about the progress of the research and get the necessary data, information and documents to conduct the following stages of the research.
The meeting were in order

5. Visiting the Library of Agriculture Research Centre (ARC)
6. Meeting with Dr Khaled Ben Mahmoud
7. Meeting with Dr Ezzeddin Rhoma
8. Visiting the Department of the Geography and Climate of the Secretary of Transportation
9. Visiting the Great Manmade River authority (GMRP)

C2-1 Visiting the Agriculture Research Centre (ARC) in Tripoli

This visit was to the library of the centre to get some documents, which cannot be borrowed, and take notes from some of these and photocopy others where it was possible.
The visit was very useful to answer questions, which have been raised, from the previous reading and writing for the parameters, which would be used to develop the suitability Framework. This involved six working days on to the ARC's library (6th of September to 11th of September).

C2-2 Meeting with Dr Khaled Ben Mahmoud

There were four meetings held with Dr Khaled R. Ben Mahmmod. He is land and soil classification experts in Libya and has been conducting research on soil in the country from the late of 1970s.There were useful discussions about the contribution to be expected from PhD research. The land qualities and characteristics selected were explained to Dr Mahmoud. There were a useful discussion and suggestion from Dr Mahmoud on the Framework.

C2-3 Meeting with Dr Ezzeddin Rhoma

Dr Ezzeddin is a soil expert in Libyan soils and he has worked in the Libyan soils area since 1978. Dr Ezzeddin will be the second member of the panel who will review the framework parameters and threshold values.

Dr Ezzeddin directed the research to Dr Ali Rhoma who is one of the economic experts in the agriculture in Libya and has been working for the last decade in this field.
The economic evaluation will follow the physical evaluation and the experience and knowledge of Dr Ali Rhoma will be used to represent the local knowledge in the economic evaluation.

C2- 4 Visiting Meteorological and climate Department (M D)

This visit included a meeting with Mr Khaled Alfathle to thank him for his efforts to ensure that the metrological data are received. These data are: Temperature and rainfall for Benina weather station in Benghazi region.

C2-5 Visiting GMRP Authority and Notes from the meeting with Mr Abudlhamed Al Shake

Abudlhamed Al Sake is the Director of the Great Manmade River (GMMR), Tripoli's office. The meeting went very well. Abudlhamed has offered every possible help to this project. Mr Al Sake stated that they just started to put some documents in a digital format and consequently there aren't currently many documents to give in a digital format. However, a CD of the path of the water from the desert was provided.

C2-5 Conclusion

The visit was a success in the collecting some data, information and documents which are urgently needed to set up the framework for land evaluation in North-East of Libya.
The data and information which could be needed will be requested from the LIB/00/004 project directly without asking any other organisation and that will save time and effort.
Dr Ben Mahmmod the head of the project offered every possible help from supplying data and documents to help with the research.

Appendix D

D1- Examples of how the suitability model works

D1-1 Example of the spreadsheet model to produce soil suitability layer

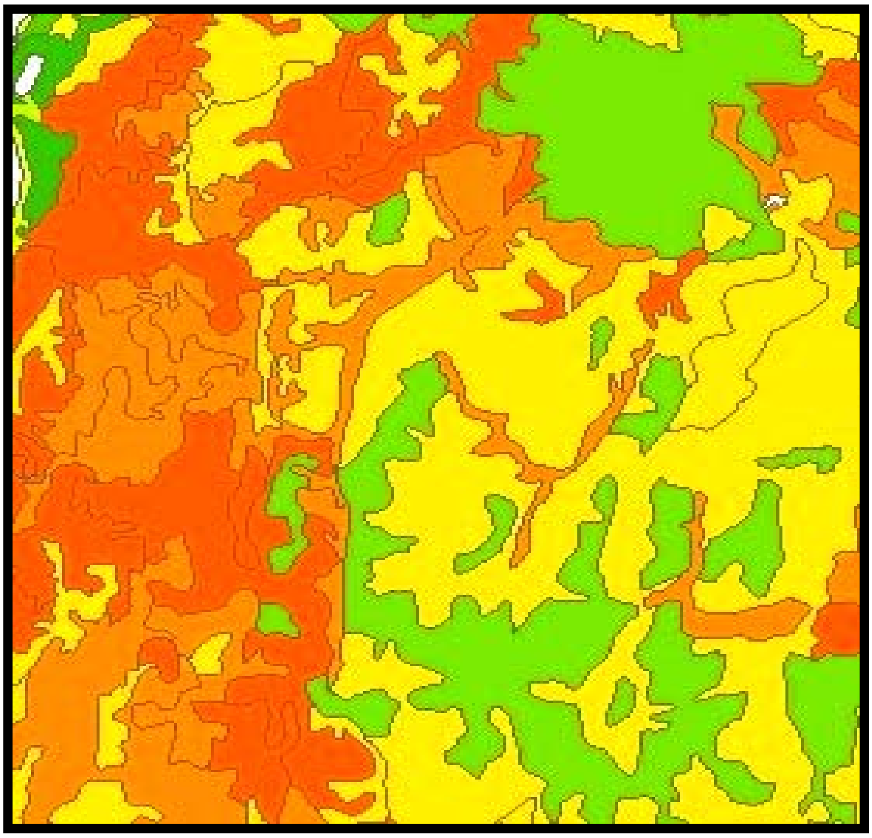
Crops			Barley				
Land Use Requirements			**Suitability Classes**				
	Land Characteristics (LC)	**Unit**	**S1**	**S2**	**S3**	**N1**	
	Rootable depth	**cm**	150	150 100	100 50	<50	
	AWHC	**mm**	175	150	100	100	
	Soil reaction	**pH**	6.5 7	5.3 6.5	5 5.3		
	Organic Matter %	**O.M**	2	1	0.5	0.5	
	Soil Salinity	**EC**	0 8	8 10	10 13	13 24	
	Cation Exchange Capacity	**CEC**	24	16	12	<12	
	Soil alkalinity	**ESP**	0	15	25	50	
	Calcium Carbonate CaCo3	**CaCo3%**	0 15	15 20	20 30	30	
	Stones	**%**	0 3	3 9	9 15	15 40	
	Soil Drainage	**Hydraulic conductivity**	300	100	40	10	
	classes	**cm/day**	100	40	10	300	
	Infiltration rate	**mm/hr**	16	10	8	> 8	

D1-2 Example of producing the suitability classes for each land characteristics and the overall land suitability

BARLEY

Land Characteristics			Ad	Bd	Bsd	CRm	CRnm
LC1	Rootable depth	cm	3	1	3	4	4
LC2	AWHC	mm	2	3	1	3	1
LC3	Soil reaction	pH	3	2	2	2	4
LC4	Organic matter	O.M %	1	3	2	2	2
LC5	Cation Exchange	CEC	2	3	3	3	3
LC6	Soil salinity	EC	1	2	1	1	1
LC7	Soil alkalinity	ESP	2	2	1	1	1
LC8	Carbonate	%	1	4	2	3	2
LC9	Stones	%	2	1	2	4	3
LC10	Soil drainage	-	2	2	2	2	2
LC11	Infiltration rate	mm/hr	2	4	4	4	4
LC 12	Soil Texture	Class	2	3	2	4	4
			Ad	**Bd**	**Bsd**	**CRm**	**CRnm**
LQ1	**Rooting Conditions**		3	1	3	4	4
LQ2	**Moisture Availability**		2	3	1	3	1
LQ3	**Nutrient Availability**		3	2	2	2	4
LQ4	**Nutrient Retention**		2	3	3	3	3
LQ5	**Excess of Salts**		2	2	1	1	1
LQ6	**Soil Toxicities**		1	4	2	3	2
LQ7	**Conditions for germinations**		2	1	2	4	3
LQ8	**Oxygen Availability**		2	2	2	2	2
LQ9	**Infiltration**		2	4	4	4	4
LQ10	**Texture**		3	3	2	3	2
Overall Suitability rating		**LUT1**	**2**	**2**	**2**	**4**	**4**

D1- 3 Example of the soil suitability layer



Appendix E

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E1- The results of the weighting schemes for the selected crops

E1-1 The results of the weighting schemes for barley

Model	S1 %	S2 %	S3 %	NS %	NODATA
1	76.4	18.1	0.2	-	5.3
2	46.6	44.0	4.1	-	5.3
3	48.5	41.6	4.6	-	5.3
4	41.6	24.0	29.1	-	5.3
5	42.0	23.4	29.3	-	5.3
6	42.0	20.7	4	28	5.3
7	46.6	42.1	6	-	5.3
8	46.6	44.0	4.1	-	5.3
9	57.0	37.7	-	-	5.3
10	85.0	9.7	-	-	5.3
11	89.0	5.7	-	-	5.3
12	94.0	-	-	-	5.3
13	54.3	35.2	5.2	-	5.3
14	46.6	44.0	4.1	-	5.3
15	49.3	45.2	0.2	-	5.3
16	69.1	25.0	0.6	-	5.3
17	70.5	23.6	0.6	-	5.3
18	75.8	15.7	3.2	-	5.3
19	51.9	12.5	28.1	-	5.3
20	46.6	44.0	4.1	-	5.3
21	57.0	37.7		-	5.3
22	79.5	2.6	12.6	-	5.3
23	82.0	0.2	12.5	-	5.3
24	82.1		12.6	-	5.3

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E1- 2 The results of the weighting schemes for wheat

Model	S1 %	S2 %	S3 %	NS %	NODATA
1	70.9	23.2	0.6	-	5.3
2	32.6	55.3	6.8	-	5.3
3	33.8	52.7	8.2	-	5.3
4	30.3	12.8	51.6	-	5.3
5	30.5	12.5	51.3	0.4	5.3
6	30.5	12.2	0.4	51.6	5.3
7	32.6	53.5	8.6	-	5.3
8	32.6	55.3	6.8	-	5.3
9	36.3	58.3	0.1	-	5.3
10	77.2	17.5	-	-	5.3
11	86.8	7.9	-	-	5.3
12	94.7	-	-	-	5.3
13	36.5	51.3	6.9	-	5.3
14	32.6	55.3	6.8	-	5.3
15	32.5	61.7	0.5	-	5.3
16	67.6	25.5	1.6	-	5.3
17	69.3	23.8	1.6	-	5.3
18	75.6	15.5	3.3	-	5.3
19	36.5	56.4	1.8	-	5.3
20	32.6	55.3	6.8	-	5.3
21	36.7	51.1	6.9	-	5.3
22	73.0	9.3	12.4	-	5.3
23	80.6	1.6	12	0.5	5.3
24	82.1	0.2	0.2	12.2	5.3

E1- 3 The results of the weighting schemes for maize

Model	S1 %	S2 %	S3 %	NS %	NODATA
1	75.2	19.2	0.3	-	5.3
2	48.2	41.4	5.1	-	5.3
3	49.8	39.3	5.6	-	5.3
4	43.3	21.2	30.2	-	5.3
5	43.6	20.9	30	0.2	5.3
6	43.6	20.9	-	30.2	5.3
7	48.2	40.5	6	-	5.3
8	48.2	41.4	5.1	-	5.3
9	61.3	33.4	-	-	5.3
10	84.0	10.7	-	-	5.3
11	89.2	5.6	-	-	5.3
12	94.7	-	-	-	5.3
13	55.4	34.4	5	-	5.3
14	48.2	41.4	5.1	-	5.3
15	48.0	46.4	0.3	-	5.3
16	69.6	24.1	1	-	5.3
17	71.0	22.7	1	-	5.3
18	75.7	15.5	3.2	0.3	5.3
19	54.2	39.7	0.8	-	5.3
20	48.2	41.4	5.1	-	5.3
21	55.3	34.0	5.4	-	5.3
22	77.9	4.1	12.7	-	5.3
23	81.4	0.8	12.5	-	5.3
24	81.9	-	-	12.8	5.3

E1- 4 The results of the weighting schemes for sorghum

Model	S1 %	S2 %	S3 %	NS %	NODATA
1	83	11.4	0.3	-	5.3
2	70.7	23.2	0.8	-	5.3
3	75	18.3	1.4	-	5.3
4	73.4	5.3	16	-	5.3
5	74.3	4.3	16	0.1	5.3
6	74.3	4.3	0.1	16	5.3
7	70.7	22.5	1.5	-	5.3
8	70.7	23.2	0.8	-	5.3
9	75.4	19.3	-	-	5.3
10	89.3	5.4	-	-	5.3
11	93.3	1.4	-	-	5.3
12	94.7	-	-	-	5.3
13	74.1	19.4	1.2	-	5.3
14	70.7	23.2	0.8	-	5.3
15	72.5	22	0.2	-	5.3
16	73.3	20.8	0.6	-	5.3
17	74.5	19.5	0.7	-	5.3
18	75.9	15.1	3.7	-	5.3
19	74.3	20.4	-	-	5.3
20	70.7	23.2	0.8	-	5.3
21	74	19.7	0.9	-	5.3
22	83.6	7.0	4.1	-	5.3
23	85.5	5.1	4	0.1	5.3
24	85.8	3.3	1.9	3.7	5.3

E2- The results of the sensitivity analysis of climate (Temperature) for the selected crops

E2-1 The results of the sensitivity analysis of climate for barley

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	27.1	61.6	6	-	5.3
2	27.1	61.6	6	-	5.3
3	27.1	61.6	6	-	5.3
4	46.5	44	4.2	-	5.3
5	46.5	44	4.2	-	5.3
6	-	85	9.7	-	5.3
7	-	85	9.7	-	5.3

E2-2 The results of the sensitivity analysis of climate for wheat

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	20.6	65.9	8.2	-	5.3
2	20.6	65.9	8.2	-	5.3
3	20.6	65.9	8.2	-	5.3
4	32.6	55.3	6.8	-	5.3
5	34.3	55.1	5.3	-	5.3
6	-	77	17	0.7	5.3
7	-	77	17	0.7	5.3

E2-3 The results of the sensitivity analysis of climate for maize

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	-	84.7	10	-	5.3
2	29.6	59.2	5.9	-	5.3
3	29.6	59.2	5.9	-	5.3
4	48.2	41.4	5.1	-	5.3
5	48.2	41.4	5.1	-	5.3
6	48.2	41.4	5.1	-	5.3
7	-	84.7	10	-	5.3

E2-3 The results of the sensitivity analysis of climate for sorghum

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1		89.6	5.1	-	5.3
2		89.6	5.1	-	5.3
3	70.7	23.2	0.8	-	5.3
4	70.7	23.2	0.8	-	5.3
5	70.7	23.2	0.8	-	5.3
6	52.1	41.2	1.4	-	5.3
7	52.1	41.2	1.4	-	5.3

E3- The results of the sensitivity analysis of Topography (slope) for the selected crops

E3-1 The results of the sensitivity analysis of slope for barley

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	17.5	69	8.2	-	5.3
2	31.5	57.7	5.2	-	5.3
3	40.6	49.6	4.5	-	5.3
4	46.6	44.0	4.1	-	5.3
5	51	39.3	-	-	5.3
6	53.2	37.2	-	-	5.3
7	53.9	36.5	-	-	5.3

E3-2 The results of the sensitivity analysis of slope for wheat

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	13.2	65.5	16.1	-	5.3
2	24.3	60.6	9.2	-	5.3
3	30	56.6	8.1	-	5.3
4	32.6	55.3	6.8	-	5.3
5	34.4	53.6	6.8	-	5.3
6	36.1	52	6.7	-	5.3
7	36.5	51.5	6.6	-	5.3

E3-3 The results of the sensitivity analysis of slope for maize

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	21.8	62.7	10.2	-	5.3
2	34.3	53.6	6.7	-	5.3
3	42.6	46.4	5.7	-	5.3
4	48.2	41.4	5.1	-	5.3
5	52.2	37.5	5	-	5.3
6	54.3	35.4	5	-	5.3
7	55	34.7	5	-	5.3

E3-4 The results of the sensitivity analysis of slope for sorghum

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	21.4	73	-	-	5.3
2	37.1	57.6	-	-	5.3
3	70.9	23	0.8	-	5.3
4	71.4	23.3	-	-	5.3
5	73.1	21.6	-	-	5.3
6	74.7	20	-	-	5.3
7	74.7	20	-	-	5.3

E4- The results of the sensitivity analysis of erosion for the selected crops

E4-1 The results of the sensitivity analysis of erosion for barley

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	46.5	43.8	4.4	-	5.3
2	46.6	44	4.1	-	5.3
3	48.5	46.2		-	5.3
4	48.5	46.2		-	5.3
5	48.7	46		-	5.3
6	48.7	46		-	5.3

E4-2 The results of the sensitivity analysis of erosion for wheat

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	32.6	54.2	7.9	-	5.3
2	32.6	54.2	7.9	-	5.3
3	35.6	59.1		-	5.3
4	35.6	59.1		-	5.3
5	52.7	38.3	4	-	5.3
6	53.3	38.5	3.2	-	5.3

E4-3 The results of the sensitivity analysis of erosion for maize

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	48.2	41.3	5.3	-	5.3
2	48.2	41.3	5.3	-	5.3
3	51.2	43.5		-	5.3
4	51.2	43.5		-	5.3
5	51.2	43.5		-	5.3
6	51.2	43.5		-	5.3

E4-4 The results of the sensitivity analysis of erosion for sorghum

Scenarios	S1 %	S2 %	S3 %	NS %	NODATA
1	68.4	25	1.3	-	5.3
2	70.7	23.2	0.8	-	5.3
3	72.5	21.6	0.6	-	5.3
4	74.1	20.6		-	5.3
5	74.3	20.4		-	5.3
6	74.7	20		-	5.3

E5- The results of the sensitivity analysis of Soil characteristics for Barley

E5-1 The scenarios of the sensitivity analysis of Rootable depth (Barley)

Scenarios	S1	S2	S3	NS
1	> 60	60-30	30-25	< 25
2	> 80	80-40	40-30	< 30
3	> 100	100-50	50-40	<40
4	> 120	120-80	80-50	< 50
5	> 150	150-100	100-60	< 50

E5-2 The results of the sensitivity analysis of Rootable depth (Barley)

Scenarios	S1 %	S2 %	S3 %	NS %
1	63.2	31.7	-	-
2	55.1	37	2.6	--
3	49.8	40	3.9	-
4	46.3	44	4.4	-
5	36	52	6.8	-

E5-3 The scenarios of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1	S2	S3	NS
1	3-2.5	2.5-1.3	1.3-1	< 1
2	5-4.5	4.5-3.3	3.3-3	< 3
3	7-6.5	6.5-5.3	5.3-5	< 5
4	9-8.5	8.5- 7.3	7.3-7	< 7
5	11-10.5	10.5-9.3	9.3-9	< 9

E5-4 The results of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1 %	S2 %	S3 %	NS %
1	48.6	46.1	-	-
2	48.6	46.1	-	-
3	46.6	44	4.1	-
4	61.1	33.6	-	-
5	48.6	46.1	-	-

E5-5 The scenarios of the sensitivity analysis of AWHC

Scenarios	S1	S2	S3	NS
1	> 100	100-90	90-40	< 40
2	> 125	125-100	100-50	< 50
3	> 175	150-110	110-75	< 75
4	> 225	225-200	200-250	< 150
5	> 300	300-250	250-200	< 200

E5-6 The results of the sensitivity analysis of AWHC

Scenarios	S1 %	S2 %	S3 %	NS %
1	78.6	16	-	-
2	49.2	45.5		--
3	46.3	44	4.4	-
4	40	49	5.7	-
5	40	49	5.7	-

E5-7 The scenarios of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1	S2	S3	NS
1	0-5	5-10	10-15	> 15
2	0-10	10-15	15-20	> 20
3	0-15	15-20	20-25	> 25
4	0-25	25-30	30-35	> 35
5	0-35	35-40	40-45	> 45

E5-8The results of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1 %	S2 %	S3 %	NS %
1	47.3	43	4.4	-
2	47.3	43	4.4	-
3	46.3	43	4.4	-
4	46.3	43	4.4	-
5	46.3	43	4.4	-

E5-9 The scenarios of the sensitivity analysis of 0.M %

Scenarios	S1	S2	S3	NS
1	> 0.5	0.5- 0.3	0.3-0.25	< 0.25
2	> 1	1-0.5	0.5-0.4	< 0.4
3	> 2	2- 1.5	1.5-1	< 1
4	> 4	4- 2	2-1.5	< 1.5
5	> 8	8- 4	4-2	< 2

E5-10 The results of the sensitivity analysis of O.M %

Scenarios	S1 %	S2 %	S3 %	NS %
1	52.2	38.4	4.2	-
2	47	43	4.4	-
3	46.3	44	4.4	-
4	46.3	44	4.4	-
5	46.3	44	4.4	-

E5-11 The scenarios of the sensitivity analysis of CEC (Barley)

Scenarios	S1	S2	S3	NS
1	> 12	12- 8	8-4	< 4
2	> 16	16-12	12-8	< 8
3	> 24	24- 16	16-12	< 12
4	> 28	28- 20	20-16	< 16
5	> 32	32- 24	24-20	< 20

E5-12 The results of the sensitivity analysis of CEC

Scenarios	S1 %	S2 %	S3 %	NS %
1	61.2	31	2.6	-
2	61.2	31	2.6	--
3	46.3	44	4.4	-
4	46.3	44	4.4	-
5	46.3	44	4.4	-

E5-13 The scenarios of the sensitivity analysis of ESP

Scenarios	S1	S2	S3	NS
1	0-1	1-2	2-2.5	< 2.5
2	0-5	5-10	10-15	< 15
3	0-15	15-25	25-50	< 50
4	0-20	20-30	30-60	< 60
5	0-30	30-40	40-80	< 80

E5-14 The results of the sensitivity analysis of ESP

Scenarios	S1 %	S2 %	S3 %	NS %
1	40.1	21.6	4.7	28.2
2	40.1	21.2	4.7	28.2
3	46.3	44	-	-
4	55.1	40.6	-	-
5	63.3	31.8	-	-

E5-15 The scenarios of the sensitivity analysis of EC

Scenarios	S1	S2	S3	NS
1	0-2	2-4	4-6	< 6
2	0-4	4-6	6-8	< 8
3	0-8	8-10	10-13	< 13
4	0-10	10-12	12-15	< 15
5	0-15	15-20	20-25	< 25

E5-16 The results of the sensitivity analysis of EC

Scenarios	S1 %	S2 %	S3 %	NS %
1	40.1	21.6	4.7	28.2
2	40.1	21.2	4.7	28.2
3	46.3	44	-	-
4	55.1	40.6	-	-
5	63.3	31.8	-	-

E5-17The scenarios of the sensitivity analysis of Infiltration

Scenarios	S1	S2	S3	NS
1	> 4	4- 6	6- 2	< 2
2	> 8	8- 10	10- 6	< 6
3	> 16	16- 12	12- 8	< 8
4	> 20	20 - 14	14- 10	< 10
5	> 22	22-16	16-14	< 14

E5-18 The results of the sensitivity analysis of Infiltration

Scenarios	S1 %	S2 %	S3 %	NS %
1	61.6	30.7	2.5	-
2	61.6	30.7	2.5	-
3	46.3	44	4.4	-
4	46.3	44	4.4	-
5	42.5	47.7	4.5	-

E5-19 The scenarios of the sensitivity analysis of Hydraulic Conductivity (Barley)

Scenarios	S1	S2	S3	NS
1	75-25	25-10	10-2.5	< 2.5
2	150-50	50-20	20-5	< 5
3	300-100	100-40	40-10	< 10
4	350-150	150-90	90-60	< 60
5	400-200	200-180	180-120	< 120

E5-20 The results of the sensitivity analysis of Hydraulic Conductivity (Barley)

Scenarios	S1 %	S2 %	S3 %	NS %
1	60.9	37.8	2.5	-
2	53	37.8	4.2	-
3	50.7	39.8	4.4	-
4	46.3	44	4.4	-
5	46.3	44	4.4	-

E5-21 The scenarios of the sensitivity analysis of Gravel and Stoniness % (Barley)

Scenarios	S1	S2	S3	NS
1	0-1.5	1.5-4.5	4.5-7.5	> 7.5
2	0-3	3-9	9-15	> 15
3	0-6	6-18	18-30	> 30
4	0-12	12-36	36-60	> 60
5	0-24	24-50	50-70	> 70

E5-22 The results of the sensitivity analysis of Gravel and Stoniness % (Barley)

Scenarios	S1 %	S2 %	S3 %	NS %
1	59.9	32.2	2.7	-
2	46.3	44	4.4	-
3	46.3	44	4.4	-
4	46.3	44	4.4	-
5	46.3	44	4.4	-

E6- The results of the sensitivity analysis of Soil characteristics for Wheat

E6-1 The scenarios of the sensitivity analysis of Rootable depth

Scenarios	S1	S2	S3	NS
1	> 60	60-30	30-25	< 25
2	> 80	80-40	40-30	< 30
3	> 100	100-50	50-40	<40
4	> 120	120-80	80-50	< 50
5	> 150	150-100	100-60	< 50

E6-2 The results of the sensitivity analysis of Rootable depth

Scenarios	S1 %	S2 %	S3 %	NS %
1	51.9	40.3	2.5	-
2	44.7	45.6	4.4	--
3	43.6	46.8	4.4	-
4	32.6	55.3	6.8	-
5	32.6	55.3	6.8	-

E6-3 The scenarios of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1	S2	S3	NS
1	3-2.5	2.5-1.3	1.3-1	< 1
2	5-4.5	4.5-3.3	3.3-3	< 3
3	7-6.5	6.5-5.3	5.3-5	< 5
4	9-8.5	8.5- 7.3	7.3-7	< 7
5	11-10.5	10.5-9.3	9.3-9	< 9

E6-4 The results of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1 %	S2 %	S3 %	NS %
1	32.6	55.3	6.8	-
2	46.7	43.9	4.1	-
3	32.6	55.3	6.8	-
4	63.2	31.2	0.3	-
5	32.6	55.3	6.8	-

E6-5 The scenarios of the sensitivity analysis of AWHC

Scenarios	S1	S2	S3	NS
1	> 100	100-90	90-40	< 40
2	> 125	125-100	100-50	< 50
3	> 175	150-110	110-75	< 75
4	> 225	225-200	200-250	< 150
5	> 300	300-250	250-200	< 200

E6-6 The results of the sensitivity analysis of AWHC

Scenarios	S1 %	S2 %	S3 %	NS %
1	36.6	58.1		-
2	36.6	58.1		-
3	32.6	55.3	6.8	-
4	22.5	66.6	3.5	-
5	24.3	70.4		-

E6-7 The scenarios of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1	S2	S3	NS
1	0-5	5-10	10-15	> 15
2	0-10	10-15	15-20	> 20
3	0-15	15-20	20-25	> 25
4	0-25	25-30	30-35	> 35
5	0-35	35-40	40-45	> 45

E6-8The results of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1 %	S2 %	S3 %	NS %
1	32.6	55.3	6.8	-
2	32.6	55.3	6.8	-
3	32.6	55.3	6.8	-
4	36	58.7	-	-
5	36	58.7	-	-

E6-9 The scenarios of the sensitivity analysis of 0.M %

Scenarios	S1	S2	S3	NS
1	> 0.5	0.5- 0.3	0.3-0.25	< 0.25
2	> 1	1-0.5	0.5-0.4	< 0.4
3	> 2	2- 1.5	1.5-1	< 1
4	> 4	4- 2	2-1.5	< 1.5
5	> 8	8- 4	4-2	< 2

E6-10 The results of the sensitivity analysis of O.M %

Scenarios	S1 %	S2 %	S3 %	NS %
1	36	58.7	-	-
2	34.3	53.9	6.5	-
3	32.6	55.3	6.8	
4	32.6	55.3	6.8	
5	32.6	55.3	6.8	

E6-11 The scenarios of the sensitivity analysis of CEC

Scenarios	S1	S2	S3	NS
1	> 12	12- 8	8-4	< 4
2	> 16	16-12	12-8	< 8
3	> 24	24- 16	16-12	< 12
4	> 28	28- 20	20-16	< 16
5	> 32	32- 24	24-20	< 20

E6-12 The results of the sensitivity analysis of CEC

Scenarios	S1 %	S2 %	S3 %	NS %
1	32.6	55.3	6.8	-
2	32.6	55.3	6.8	-
3	32.6	55.3	6.8	-
4	34.9	59.7	-	-
5	34.9	59.7	-	-

E6-13 The scenarios of the sensitivity analysis of ESP

Scenarios	S1	S2	S3	NS
1	0-1	1-2	2-2.5	< 2.5
2	0-5	5-10	10-15	< 15
3	0-15	15-25	25-50	< 50
4	0-20	20-30	30-60	< 60
5	0-30	30-40	40-80	< 80

E6-14 The results of the sensitivity analysis of ESP

Scenarios	S1 %	S2 %	S3 %	NS %
1	44.5	46.1	4.1	-
2	32.6	55.3	6.8	-
3	32.6	55.3	6.8	-
4	34.9	59.8	-	-
5	34.9	59.8	-	-

E6-15 The scenarios of the sensitivity analysis of EC

Scenarios	S1	S2	S3	NS
1	0-2	2-3.4	3.4-5.5	< 5.5
2	0-4	4-5.4	5.4-7.5	< 7.5
3	0-6	6-7.4	7.4 -9.5	< 9.5
4	0-8	8-9.4	12-15	< 11.5
5	0-10	10-11.5	11.5-13.5	< 13.5

E6-16 The results of the sensitivity analysis of EC

Scenarios	S1 %	S2 %	S3 %	NS %
1	32.3	56.4	6	-
2	39.4	50.3	4.9	-
3	32.6	55.3	6.8	-
4	32.6	55.3	6.8	-
5	32.6	55.3	6.8	-

E6-17 The scenarios of the sensitivity analysis of Infiltration

Scenarios	S1	S2	S3	NS
1	> 4	4- 6	6- 2	< 2
2	> 8	8- 10	10- 6	< 6
3	> 16	16- 12	12- 8	< 8
4	> 20	20 - 14	14- 10	< 10
5	> 22	22-16	16-14	< 14

E6-18 The results of the sensitivity analysis of Infiltration

Scenarios	S1 %	S2 %	S3 %	NS %
1	52.6	40.2	1.9	-
2	60.2	32	2.5	-
3	32.6	55.3	6.8	-
4	34.1	53.8	6.8	-
5	33.9	53.9	6.9	-

E6-19 The scenarios of the sensitivity analysis of Hydraulic Conductivity

Scenarios	S1	S2	S3	NS
1	75-25	25-10	10-2.5	< 2.5
2	150-50	50-20	20-5	< 5
3	300-100	100-40	40-10	< 10
4	350-150	150-90	90-60	< 60
5	400-200	200-180	180-120	< 120

E6-20 The results of the sensitivity analysis of Hydraulic Conductivity

Scenarios	S1 %	S2 %	S3 %	NS %
1	50.9	39	4.8	-
2	50.9	39	4.8	-
3	32.6	55.3	6.8	-
4	32.6	55.3	6.8	-
5	32.6	55.3	6.8	-

E6-21 The scenarios of the sensitivity analysis of Gravel and Stoniness % (Wheat)

Scenarios	S1	S2	S3	NS
1	0-1.5	1.5-4.5	4.5-7.5	> 7.5
2	0-3	3-9	9-15	> 15
3	0-6	6-18	18-30	> 30
4	0-12	12-36	36-60	> 60
5	0-24	24-50	50-70	> 70

E6-22 The results of the sensitivity analysis of Gravel and Stoniness % (Wheat)

Scenarios	S1 %	S2 %	S3 %	NS %
1	32.6	55.3	6.8	-
2	42.1	48.2	4.4	-
3	59.7	32.5	2.5	-
4	32.6	55.3	6.8	-
5	52.6	37.6	4.6	-

E7- The results of the sensitivity analysis of Soil characteristics for Maize

E7-1 The scenarios of the sensitivity analysis of Rootable depth

Scenarios	S1	S2	S3	NS
1	> 60	60-30	30-25	< 25
2	> 80	80-40	40-30	< 30
3	> 100	100-50	50-40	<40
4	> 150	120-80	80-50	< 50
5	> 300	300-150	150-100	<100

E7-2 The results of the sensitivity analysis of Rootable depth

Scenarios	S1 %	S2 %	S3 %	NS %
1	48.9	41.2	4.7	-
2	48.9	41.2	4.7	--
3	48.9	41.2	4.7	-
4	48.2	41.5	4.7	-
5	45	44.1	5.6	-

E7-3 The scenarios of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1	S2	S3	NS
1	3-2	2 -1	1.3-1	< 1
2	5-4	4-3	3 -2	< 2
3	7-6	6 -5	5-4	< 4
4	9-8	8. - 7.	7- 6	< 6
5	11-10	10-9	9.3-9	< 8

E7-4 The results of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1 %	S2 %	S3 %	NS %
1	45.5	44.7	4.6	-
2	45.5	44.7	4.6	--
3	48.2	41.5	4.7	-
4	54	37.6	2.6	-
5	53.2	38.6	2.9	-

E7-5 The scenarios of the sensitivity analysis of AWHC

Scenarios	S1	S2	S3	NS
1	> 100	100-90	90-40	< 40
2	> 125	125-100	100-50	< 50
3	> 175	150-110	110-75	< 75
4	> 225	225-200	200-250	< 150
5	> 300	300-250	250-200	< 200

E7-6 The results of the sensitivity analysis of AWHC

Scenarios	S1 %	S2 %	S3 %	NS %
1	45.7	44.5	4.5	-
2	45.7	44.5	4.5	--
3	48.2	41.5	4.7	-
4	43.8	41.5	5.1	-
5	42	46.9	5.8	-

E7-7 The scenarios of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1	S2	S3	NS
1	0-5	5-10	10-15	> 15
2	0-10	10-15	15-20	> 20
3	0-15	15-20	20-25	> 25
4	0-25	25-30	30-35	> 35
5	0-35	35-40	40-45	> 45

E7-8The results of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1 %	S2 %	S3 %	NS %
1	51.9	39.9	2.9	-
2	51.9	39.9	2.9	-
3	48.2	41.5	4.7	-
4	53.5	41.2	-	-
5	53.5	41.2	-	-

E7-9 The scenarios of the sensitivity analysis of 0.M %

Scenarios	S1	S2	S3	NS
1	> 0.5	0.5- 0.3	0.3-0.25	< 0.25
2	> 1	1-0.5	0.5-0.4	< 0.4
3	> 2	2- 1.5	1.5-1	< 1
4	> 4	4- 2	2-1.5	< 1.5
5	> 8	8- 4	4-2	< 2

E7-10 The results of the sensitivity analysis of O.M %

Scenarios	S1 %	S2 %	S3 %	NS %
1	55.1	39.6	-	-
2	55.1	39.6	-	-
3	48.2	41.5	4.7	-
4	48.2	41.5	4.7	-
5	26.6	61.1	7	-

E7-11 The scenarios of the sensitivity analysis of CEC

Scenarios	S1	S2	S3	NS
1	> 12	12- 8	8-4	< 4
2	> 16	16-12	12-8	< 8
3	> 24	24- 16	16-12	< 12
4	> 28	28- 20	20-16	< 16
5	> 32	32- 24	24-20	< 20

E7-12 The results of the sensitivity analysis of CEC

Scenarios	S1 %	S2 %	S3 %	NS %
1	57.5	34.5	2.8	-
2	44.1	45.1	5.5	--
3	48.2	41.5	4.7	-
4	44.1	45.1	5.5	-
5	26.7	61	7	-

E7-13 The scenarios of the sensitivity analysis of ESP

Scenarios	S1	S2	S3	NS
1	0-1	1-2	2-2.5	> 2.5
2	0-5	5-10	10-15	> 15
3	0-15	15-25	25-50	> 50
4	0-20	20-30	30-60	> 60
5	0-30	30-40	40-80	> 80

E7-14 The results of the sensitivity analysis of ESP

Scenarios	S1 %	S2 %	S3 %	NS %
1	43.8	48.3	2.6	
2	44	48.3	2.5	
3	48.2	41.5	4.7	
4	44.3	48.3	2.5	
5	45.2	49.5	-	

E7-15 The scenarios of the sensitivity analysis of EC

Scenarios	S1	S2	S3	NS
1	0-0.85	0.85-1.5	1.5-1.85	< 1.85
2	0-1.7	1.7-2.5	6-8	< 5.9
3	0-3.4	3.4-5	5-7.4	< 7.4
4	0-6.8	6.8-10	10-14	< 14
5	0-13.6	13.6-20	20-29	< 29

E7-16 The results of the sensitivity analysis of EC

Scenarios	S1 %	S2 %	S3 %	NS %
1	43.1	46.3	5.6	-
2	43.7	48.4	2.6	-
3	48.2	41.5	4.7	-
4	43.7	48.6	2.6	-
5	26.7	61	7	-

E7-17The scenarios of the sensitivity analysis of Infiltration

Scenarios	S1	S2	S3	NS
1	> 4	4- 6	6- 2	< 2
2	> 8	8- 10	10- 6	< 6
3	> 16	16- 12	12- 8	< 8
4	> 20	20 - 14	14- 10	< 10
5	> 22	22-16	16-14	< 14

E7-18 The results of the sensitivity analysis of Infiltration

Scenarios	S1 %	S2 %	S3 %	NS %
1	61.3	30.9	2.6	-
2	60.9	31.2	2.6	-
3	48.2	41.5	4.7	-
4	42.2	47.8	4.7	-
5	42.2	47.8	4.7	-

E7-19 The scenarios of the sensitivity analysis of Hydraulic Conductivity (Barley)

Scenarios	S1	S2	S3	NS
1	75-25	25-10	10-2.5	< 2.5
2	150-50	50-20	20-5	< 5
3	300-100	100-40	40-10	< 10
4	350-150	150-90	90-60	< 60
5	400-200	200-180	180-120	< 120

E7-20 The results of the sensitivity analysis of Hydraulic Conductivity (Barley)

Scenarios	S1 %	S2 %	S3 %	NS %
1	39.8	50.5	4.4	-
2	60.6	31.6	2.6	-
3	48.2	41.5	4.7	-
4	59.7	32.3	2.8	-
5	50.4	39.8	4.5	-

E7-21 The scenarios of the sensitivity analysis of Gravel and Stoniness %

Scenarios	S1	S2	S3	NS
1	0-1.5	1.5-4.5	4.5-7.5	> 7.5
2	0-3	3-9	9-15	> 15
3	0-6	6-18	18-30	> 30
4	0-12	12-36	36-60	> 60
5	0-24	24-50	50-70	> 70

E7-22 The results of the sensitivity analysis of Gravel and Stoniness % (Barley)

Scenarios	S1 %	S2 %	S3 %	NS %
1	59.9	32.2	2.7	-
2	48.2	41.5	4.7	-
3	48.2	41.5	4.7	-
4	46.3	44	4.4	-
5	46.3	44	4.4	-

E8- The results of the sensitivity analysis of Soil characteristics for Sorghum

E8-1 The scenarios of the sensitivity analysis of Rootable depth

Scenarios	S1	S2	S3	NS
1	> 60	60-30	30-25	< 25
2	> 80	80-40	40-30	< 30
3	> 100	100-50	50-40	<40
4	> 120	120-80	80-50	< 50
5	> 300	300-150	150-100	<100

E8-2 The results of the sensitivity analysis of Rootable depth

Scenarios	S1 %	S2 %	S3 %	NS %
1	72.6	21.5	1.1	-
2	72.6	21.5	1.1	-
3	70.9	23	0.8	-
4	70.9	23	0.8	-
5	68.3	25.6	0.8	-

E8-3 The scenarios of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1	S2	S3	NS
1	4-2.5	2.5 -2	2-1	< 1
2	6- 4	4- 3.5	3.5 -3	< 3
3	8- 6	6- 5.5	5.5 -5	< 5
4	10-8	8 - 7.5	7.5- 7	< 7
5	12-10	10-9	9.5-9	< 9

E8-4 The results of the sensitivity analysis of Soil reaction (pH)

Scenarios	S1 %	S2 %	S3 %	NS %
1	68.8	25.9	-	-
2	68.8	25.9	-	-
3	70.9	23	0.8	-
4	72.2	22.1	-	-
5	68.8	25.9	-	-

E8-5 The scenarios of the sensitivity analysis of AWHC

Scenarios	S1	S2	S3	NS
1	> 100	100-90	90-40	< 40
2	> 125	125-100	100-50	< 50
3	> 150	150-110	110-75	< 75
4	> 225	225-200	200-250	< 150
5	> 300	300-250	250-200	< 200

E8-6 The results of the sensitivity analysis of AWHC

Scenarios	S1 %	S2 %	S3 %	NS %
1	70.5	22.9	0.7	-
2	70.5	22.9	0.7	-
3	70.9	23	0.8	-
4	62.9	30.7	1.1	-
5	52.8	40.5	1.4	-

E8-7 The scenarios of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1	S2	S3	NS
1	0-5	5-10	10-15	> 15
2	0-10	10-15	15-20	> 20
3	0-15	15-20	20-25	> 25
4	0-25	25-30	30-35	> 35
5	0-35	35-40	40-45	> 45

E8-8The results of the sensitivity analysis of $CaCO_3$ %

Scenarios	S1 %	S2 %	S3 %	NS %
1	70.5	22.9	0.7	-
2	70.5	22.9	0.7	-
3	70.9	23	0.8	-
4	70.9	23	0.8	-
5	70.9	23	0.8	-

E8-9 The scenarios of the sensitivity analysis of 0.M %

Scenarios	S1	S2	S3	NS
1	> 0.5	0.5- 0.3	0.3-0.25	< 0.25
2	> 1	1-0.5	0.5-0.4	< 0.4
3	> 2	2- 1.5	1.5-1	< 1
4	> 4	4- 2	2-1.5	< 1.5
5	> 8	8- 4	4-2	< 2

E8-10 The results of the sensitivity analysis of O.M %

Scenarios	S1 %	S2 %	S3 %	NS %
1	70.5	22.9	0.7	-
2	70.5	22.9	0.7	-
3	70.9	23	0.8	-
4	70.9	23	0.8	-
5	70.9	23	0.8	-

E8-11 The scenarios of the sensitivity analysis of CEC

Scenarios	S1	S2	S3	NS
1	> 12	12- 8	8-4	< 4
2	> 16	16-12	12-8	< 8
3	> 24	24- 16	16-12	< 12
4	> 28	28- 20	20-16	< 16
5	> 32	32- 24	24-20	< 20

E8-12 The results of the sensitivity analysis of CEC

Scenarios	S1 %	S2 %	S3 %	NS %
1	78	15.9	0.7	-
2	70.5	22.9	0.7	--
3	70.9	23	0.8	-
4	70.9	23	0.8	-
5	70.9	23	0.8	-

E8-13 The scenarios of the sensitivity analysis of ESP

Scenarios	S1	S2	S3	NS
1	0-1	1-2	2-2.5	> 2.5
2	0-5	5-10	10-15	> 15
3	0-15	15-25	25-50	> 50
4	0-20	20-30	30-60	> 60
5	0-30	30-40	40-80	> 80

E8-14 The results of the sensitivity analysis of ESP

Scenarios	S1 %	S2 %	S3 %	NS %
1	60.6	33.4	0.7	-
2	60.6	33.4	0.7	-
3	70.9	23	0.8	-
4	70.9	23	0.8	-
5	70.9	23	0.8	-

E8-15 The scenarios of the sensitivity analysis of Infiltration

Scenarios	S1	S2	S3	NS
1	> 4	4- 6	6- 2	< 2
2	> 8	8- 10	10- 6	< 6
3	> 16	16- 12	12- 8	< 8
4	> 20	20 - 14	14- 10	< 10
5	> 22	22-16	16-14	< 14

E8-16 The results of the sensitivity analysis of Infiltration

Scenarios	S1 %	S2 %	S3 %	NS %
1	75.5	5	7.6	-
2	75.5	5	7.6	-
3	70.9	23	0.8	-
4	70.9	23	0.8	-
5	70.9	23	0.8	-

E8-17 The scenarios of the sensitivity analysis of Hydraulic Conductivity

Scenarios	S1	S2	S3	NS
1	75-25	25-10	10-2.5	< 2.5
2	150-50	50-20	20-5	< 5
3	300-100	100-40	40-10	< 10
4	350-150	150-90	90-60	< 60
5	400-200	200-180	180-120	< 120

E8-18 The results of the sensitivity analysis of Hydraulic Conductivity

Scenarios	S1 %	S2 %	S3 %	NS %
1	70.4	22.9	1.4	-
2	70.4	22.9	1.4	-
3	70.9	23	0.8	-
4	70.1	23.2	1.4	-
5	70.1	23.2	1.4	-

E8-19 The scenarios of the sensitivity analysis of Gravel and Stoniness %

Scenarios	S1	S2	S3	NS
1	0-1.5	1.5-4.5	4.5-7.5	> 7.5
2	0-3	3-9	9-15	> 15
3	0-6	6-18	18-30	> 30
4	0-12	12-36	36-60	> 60
5	0-24	24-50	50-70	> 70

E8-20 The results of the sensitivity analysis of Gravel and Stoniness %

Scenarios	S1 %	S2 %	S3 %	NS %
1	68.8	25.9	-	-
2	70.9	23	0.8	-
3	70.9	23	0.8	-
4	70.9	23	0.8	-
5	70.9	23	0.8	-