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DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR SOIL SUITABILITY EVALUATION FOR ARABLE CROPS

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ABSTRACT

The study designed a decision support system for soil suitability evaluation for arable crops. Implementation and evaluation of the system were subsequently carried out. This was with a view to make optimal decision on crop cultivation.

Data on soil and climatic requirements for planting maize, cowpea, tomatoes and okro were collected from agricultural science expert. The data collected were used to design the knowledge model of the decision support system. The system was designed using unified modelling language (UML) and its intelligence was modelled using fuzzy inference engine. The model was implemented using Matlab. Evaluation of the system was quantitatively determined using accuracy as performance matrix and qualitatively done by comparing its output with those from experts using the mean opinion score.

The system's overall accuracy was 92.7%. The inference system to determine soil suitability for cowpea had 98.8% accuracy, 96.8% accuracy for maize, 88.2% accuracy for okro and 86.8% accuracy for tomatoes. The overall rating of the system by experts in terms of its output was 4.40/5.00 (88%), which is an indication of a good measure of reliability of the system.

The system developed is capable of providing information on soil suitability evaluation for efficient land use.

Keywords : decision support system for soil, soil suitability evaluation for arable crops, crop cultivation,

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CHAPTER ONE

INTRODUCTION

1.1 Synopsis

Soil is a component of the natural medium that acquires its morphology and properties after a long and slow evolution after reaching an equilibrium with environmental conditions (Dorronsoro, 2002). It is, thus, a natural entity, which does not anticipate human use in its evolution. Soil has undergone intensive exploitation due to the shift from hunting and gathering to farming and herding. Several years of irrational soil use by humans has transpired, with no objective beyond seeking maximum yield from every kind of soil use. As a result, the present day soil is intensely degraded to the point that a great part of arable land especially, in arid and semiarid regions, is in a condition of irreversible deterioration (Dorronsoro, 2002). To reduse this dramatic trend, the only solution is to institute rational soil use that is, to use each soil in a way that best suits its characteristics and to programme its management for minimal degradation. This is precisely the aim of land evaluation.

The need for optimum use of land has never been greater than at present, when rapid population growth and urban expansion are turning land into a relatively scarce commodity for agriculture.

Land evaluation is an applied classification system that assesses the capacity of the soil for its optimal use that is, to derive maximum benefits with minimum degradation. This can be defined, according to Van Diepen *et al*. (1991), as “any method to explain or predict the potential use of land”.

Different types of soils present widely different properties, and therefore, the response to each use differs. Land evolution is based on the idea that which response is a function of which properties, and, hence, knowing these, one can predict the behaviour of the soil under a given use. From the study of such properties, different degrees of suitability of the soil can be inferred for each end. These degrees are reflected on maps of use capacity or suitability, on which the corresponding recommendations are made for the rational planning of soil use.

As land evaluation is intended to offer practical results that can be plotted on territorial maps, such endeavours cannot be limited to the analysis of the physical medium of the earth, but rather must be complemented by the corresponding socio-economic studies that enable cost-benefit analyses of the profitability of the land used. Thus, land evaluation enables predictions on the biophysical and economic behaviour of land for current and potential uses.

At first, the terms “soil evaluation” and “land evaluation” were used interchangeably, but soon the term land evaluation became predominant and soil evaluation fell into disuse. The use of the term soil evaluation in its broadest sense was proposed, extending its meaning to all the characteristics that affect the soil, whether these be soil properties themselves or any related to the soil surface. Soil evaluation would be similar to what today is called land evaluation.

With fluctuating rainfall patterns or higher frequency of dry periods, efficient land utilization for agricultural production systems is required for the survival of most farms in Nigeria. Therefore land evaluation techniques and their resulting soil or land suitability must address the economic viability and provide information for management decisions at field or farm scale. Modern precision agricultural practices require across-farm and/or within-field soil variability which should be accounted for in the suitability assessment for it to be an effective tool for management decisions. Soil function under a number of land uses should also be assessed as it provides different options to the farmer and thus reduces the farmer’s dependency on a single land use. There is therefore the need to explore simultaneous soil suitability analysis for several viable crops to determine the overall suitability or versatility.

Each plant specie requires definite soil and site conditions for its optimum growth. Although some plants may be found to grow under different soils and extreme agro-ecological conditions, yet not all plants can grow on the same soil and under the same environment. Since the availability of both water and plant nutrients is largely controlled by the physicochemical and micro environment of soils, the success and/or failure of any plant species, in a particular area, is largely determined by these factors. The deep rooted forest or orchard plantations respond differently to soil depth and soil texture (Mishra and Sahu,1991) than the shallow-rooted arable crops such as rice, wheat, green gram, black gram, pigeon-pea, groundnut etc.

Emerging technology in data and knowledge engineering provides excellent possibilities in land evaluation development and application processes. The application phase of land evaluation systems is a process of scaling-up from the representative areas of the development phase to implementation in unknown scenarios. The application phase previously accomplished manually can now be executed with computer-assisted procedures. This involves the development and linkage of integrated databases, computer programs, and spatialization tools, constituting decision support systems (De la Rosa and Van Diepen, 2002).

1.2 Need for land suitability evaluation

Land evaluation is formally defined as the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 1976).

Evaluating land suitability and selecting crops in modern agriculture is of critical importance to every organization. This is because the narrower the area of land, the more effectiveness in planting is required in accordance with the desires of the land. The process of evaluating land suitability class and selecting plants in accordance with decision marker's requirements is complex and unstructured (Hartati and Sitanggang, 2010).

Land evaluation is carried out to estimate the suitability of land for a specific use such as arable farming or irrigated agriculture. Land evaluation can be carried out on the basis of biophysical parameters and/or socioeconomic conditions of an area (FAO, 1976). Biophysical factors tend to remain stable, unlike socioeconomic factors that are affected by social, economic, and political settings (Dent and Young, 1980). Thus, physical land suitability evaluation is a prerequisite for land-use planning and development (Van Ranst *et al.*, 1996). It provides information on the restrictions and opportunities for the use of the land and therefore, guides decisions on optimal utilization of land resources.

1.3 Land Suitability Evaluation

As stated above, land suitability is the ability of a given type of land to support a define use or practice. The main objective of the land evaluation is prediction of inherent capacity of the land units without deterioration (Elaalem *et al.,* 2001). Land suitability evaluation is an interdisciplinary approach by including the information from different domains like soil science, crop science, meteorology, social science, economics and management.

In order to circumvent this vagueness in land evaluation, fuzzy set method which is a quantitative approach that estimates the suitability of land on a continuous scale (e.g 0-1), rather than the grouping of land into discrete capability units was explored in this study. Fuzzy logic allows an overlap of classes in the attribute space. It enables different land characteristics that determine land suitability to be assessed in concert, rather than individually by separate rules (Van Ranst *et al*., 1996). Fuzzy techniques are flexible in that they capture the continuous variation of soil properties and help to deal with vagueness and imprecision associated with natural resource data (Burrough, 1989; Braimoh *et al*., 2004; Samranpong *et al*., 2009).

1.4 The Objectives of Land Evaluation

Land evaluation supports many other disciplines. It may be used for many purposes, ranging from land use planning to exploring the potential for specific land uses or the need for improved land management or land degradation control. The primary objective of land evaluation is the improved and sustainable management of land for the benefit of the people. The aims of land evaluation as given in the original framework remain wholly valid; where these refer to the identification of adverse effects and benefits of land uses, there is now a greater emphases of environmental consequences and wider benefits on environmental and ecosystem services.

Land evaluation is primarily the analysis of data on land –its soils, climate, vegetation, etc. – in terms of realistic alternatives for improving the use of that land (FAO, 2007). It is true that uses which are socially or economically unrealistic, for example large-scale mechanized agriculture in areas already densely settled, are excluded at an early stage, and left out of the analysis. Nevertheless, land evaluation focuses on the land itself, its properties, functions and potential.

1.5 Decision Support System

Decision Support System (DSS) can be defined as an interactive computer-based system that can help to utilize data and models to solve a decision problem (Malczewski, 1999). As computer tools, they are generally understood as an extension of commonly known expert systems – the systems derived from Artificial Intelligence field (AI). The expert systems' definition "enhancement" allows, among other differences, to use "black box" models in contrast to the classical hard AI systems, where the system behavior is algorithmic, thus understandable on the every level of its action. DSS exploit every available techniques of data processing to the benefit of accuracy of decision making support. This includes fuzzy as well. Every DSS has to include basic set of elements namely: Knowledge base, model or so-called inference machine and user interface (Hand *et al*., 2001)

A knowledge base usually consists of all available information gathered in the strictest organizational way that is possible to. This includes data-formatting and pre-processing in order to make it easier to be processed by any numerical analysis tools to be employed in the future. It is a very tedious and complicated task and is also crucial to the future system accuracy. Knowledge sources might be categorized into two main classes: empirical results and theoretical background. If available, both sources might be combined to the benefit of the DSS.

The user interface is a final part of DSS to be prepared and it is strictly dependent on the particular problem specifics. The function of the user interface is to present questions and information to the user and supply the user's responses to the inference engine.

1.6 Fuzziness in Land Suitaaability Decision Making

Fuzzy logic is an attempt to extend the concept of continuous variation of soil properties from the geographic space to the attribute space (Burrough *et al*., 1997). The use of fuzzy technique in this study is to predict land suitability for crops in a continuous scale. Land suitability indices reflect inherent fertility of the soils (Braimoh *et al*., 2004). The approach in this research is well applicable for applications in which subtle differences in land characteristic is of the major interests. Considering major constraints to the use of fuzzy technique for land suitability evaluation, it results in valuable information for identifying major limitations to crops production and strategies for overcoming them. The most important factor that complicates a decision making problem, is the domination of uncertainty situation. Decision making under uncertainty situation is complex and difficult, thus achieving a suitable and optimum choice demands compliance with rules, values and different description aspects of decision process. Fuzzy set theory can continually show land continuity in different land classes and this is one of its advantages. The other advantage is that it allows the environment to be inherently vague and does not try to limit soil continual system to the data measured by soil science researchers (Burrough *et al.,* 1992).

1.7 Statement of Problem

Soil suitability evaluation for crop cultivation in modern agriculture is of critical importance due to limited availability of arable land. However, the conventional evaluation method for land is cumbersome and inefficient. There is therefore, the need for a system to predict land suitability for different crops, hence the need for this study.

1.8 Rationale for the Research

The need to evaluate land suitability and crop selection in modern agriculture is of critical importance to every organization. This is because the narrower area of land, the more the effectiveness in planting required in accordance with the desires of the land. The problem of selecting suitable land to cultivate appropriate agricultural products is a long-standing and mainly empirical issue. Although, many researchers, organizations, institutes and governments have tried to provide a framework for optimal agricultural land use, most of agricultural land is still being used below its optimal capability. Based on these reasons, a decision support system is needed to assist decision makers for solving unstructured problems.

1.9 Scope

This study focuses on assessing land suitability of arable crops (maize, cowpea, tomatoes and okro) in South Western Nigeria.

1.10 Research Aim and Objectives

The aim of this research is to develop a soil suitability evaluation system to make optimal decision on crop cultivation. The specific objectives are to:

(a) design a model to determine appropriate land for crops

(b) implement a decision support system based on the model in (a); and

(c) evaluate the system implemented.

1.11 Research Methodology

Data was collected from agricultural science experts on soil and climatic requirements for the planting of maize, cowpea, tomatoes and okro. The data collected were used to design the knowledge model of the decision support system. The system was designed using Unified Modelling Language (UML) and its intelligence was modelled using fuzzy inference engine. The model was implemented using Matlab. Evaluation of the system was quantitatively done by comparing the output from the system with experts using the mean opinion score.

1.12 Contribution to Knowledge

The study contributed to the existing body of knowledge by developing a model that provide information on soil suitability evaluation for arable crops in south western Nigeria for efficient land use.

1.13 Organization of the Thesis

Chapter two discusses the background concept and the review of literature. In chapter three, the methodology used to achieve the research objectives was described. Chapter four presents the implementation and evaluation of the model developed in chapter 3. Chapter five concludes the thesis with a summary of the work done, the conclusion and some recommendation for future works. The references and the appendices were also presented.

CHAPTER TWO

BACKGROUND CONCEPTS AND LITERATURE REVIEW

2.1 Preamble

This chapter gives the background knowledge about some basic concepts and principles used throughout the thesis. An extensive survey of the soil suitability evaluation concepts and decision support system is presented. Also, the theoretical knowledge about the existing literatures is presented; discussing their goals, the methodology used, the results obtained, their contribution to studies and their weaknesses.

2.2 Overview of Soil Suitability Evaluation

Soil, being the natural medium for plant growth has a direct impact on yield and quality of crops growing on it. In Nigeria, a recent general reduction in the yield of common crops has drawn attention of stakeholders in the agricultural sector to this serious trend. Therefore, the greatest challenge before Nigerian agriculture is to boost food production and productivity as well as sustainability of agriculture as a whole (FAO Handbook, 2004). There are problems that impose limits on these objectives or goals which raise serious concerns about national food security. These include deterioration of soil fertility, increase in cost of production, and low diversity of production systems (Arifalo and Mafimisebi, 2011). However, the need for improved crop productivity is more now than ever because the increasing rate of population growth at about 3% in Nigeria

(CIA, 2012) and the consequent pressures from competing demands for land over time have resulted in cultivatable land being drawn from its traditional agricultural uses. With the resultant reduction in land-man ratio this has drastically reduced the average size of farm land and invariably leads to soil fertility depletion through continuous or intensive cropping along with short, unfertilized fallow (Adesimi, 1988)

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 is carried out to estimate the suitability of land for a specific use such as arable farming or irrigated agriculture. Land evaluation as a term has been developing over recent decades.

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 recognized 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 Stalinization".

Land evaluation is an applied classification system that assesses the capacity of the soil for its optimal use that is, to derive maximum benefits with minimum degradation. This can be defined, according to (Van Diepen *et al*., 1991), as "any method to explain or predict the use potential of land".

Land evaluation is a process for predicting land suitability class of a given area. It is very important for agriculture, especially in determining which crops are appropriate for a given area, or alternatively, given crops, what types of soil is appropriate to plant in. Land evaluation can be automated using a computer system, a fuzzy knowledge based system, which emulates the decision-making process of an agriculture expert.

2.3 Land Suitability Concepts

Determining suitable land for a particular use is a complex process involving multiple decisions that may relate to biophysical, socio-economic and institutional/organizational aspects. A structured and consistent approach to land suitability evaluation is therefore essential. Abiotic (such as rainfall, humidity), biotic (pest and disesases), and socio-economic factors decide the success of a crop.

2.4 The FAO-Sys Model for Land Evaluation

The FAO (FAO, 1976) method is not a ready-made, detailed land evaluation scheme. Instead, it is a flexible framework supplemented by guidelines to create specific evaluation. It describes how to carry out an evaluation exercise, including how to select land uses to evaluate. It also describes what factors (land qualities) to consider when evaluating for certain general kinds of land uses (e.g. forestry), and how to evaluate these qualities (Rossiter, 1994).

The above method must be supplemented with an analytical method, which will infer from the set of land characteristics that affect a land use to the severity levels of the land quality. Sys, presents a variance of the method of matching tables, which assigns the correct severity level of the land quality, given data values for each land characteristic (Sys, 1985). Matching tables are also called 'maximum limitation' tables. They are in the form of a matrix, with the rows being the different land characteristics, the columns being the (classified) land quality ratings, and the cells being the value of the land characteristic (row) that must be met or exceeded in order for the land quality to be rated in the severity level indicated by the column. Thus, matching tables limit the land quality rating to the most limiting value of the set of diagnostic land characteristics. The advantages of this method are that it is simple, easy-to-understand, and has a graphical presentation. However, it has the disadvantage that it can't account for interactions between land characteristics.

The FAO-SYS system is a land evaluation model, which is based on FAO's framework and guidelines for land evaluation and Sys's variance of the analytical method of matching tables. According to FAO-SYS, sixteen land characteristics are analyzed, and the suitability of land is evaluated. The classes of suitability indicate the degree of suitability, not simply suitable vs. not suitable. 'S1' = suitable, 'S2' = moderately suitable, 'S3' = marginally suitable, 'N1' unsuitable for economic reasons but otherwise marginally suitable, 'N2' = unsuitable for physical reasons. The linguistic terms 'moderately' and 'marginal' are given specific meanings in the course of the evaluation. N2 implies limitations that are not correctable at any cost within the context of the land utilization type.

The FAO Framework of land evaluation is developed from earlier land capability approaches. Here, overall land suitability of a land area for a certain land use is evaluated from a set of more-or-less independent land qualities, which may each limit the land use potential. These evaluations often classify map units of natural resource inventories. Hereby, legend categories of soil survey are classified into suitability subclasses, based on the number and severity of limitations of land use.

The FAO Framework identifies four categories of increasing details, as shown in Table 2.1. There are four categories recognized for classification of land suitability (FAO, 1983):

a. Land Suitability Orders: suitability orders indicate in the simplest form whether land is suitable or not suitable, for specified use. Whereas S = Suitable, N = Not suitable for the land use.

b. Land Suitability Classes: suitability classes show the degree of suitability within an order. The following are the land suitability classes:

i) S1 (highly suitable) – land having no significant limitations to sustained application of a given use.

SN	Categories	Explanation
1	Land Suitability Orders	Reflecting kinds of suitability

Table 2.1: FAO Structure of Land Suitability Classification

2	Land suitability Classes	Reflecting degrees of suitability within Orders
3	Land Suitability Subclasses	Reflecting kinds of limitation, or main kind of improvement measures required, within classes.
4	Land Suitability Units	Reflecting minor differences in required management within subclasses

ii) S2 (moderately suitable) – land having limitations which in aggregate are moderately severe for a sustained application of a given use.

iii) S3 (marginally suitable) - land having limitations which in aggregate are severe for sustained application of a given use and will reduce productivity or benefits.

iv) N1 (currently not suitable) - land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.

v) N2 (permanently not suitable) – land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land of a given land use.

c. Land Suitability Subclasses: subclasses reflect kinds of limitation or required improvements measures within classes.

d. Land Suitability Units: indicating differences in required management within subclasses.

Based on the scale of measurement of the suitability there are two types of classifications in FAO framework

i) Qualitative: the classes are evaluated based on physical production potential of the land, commonly employed in reconnaissance studies. It is used to evaluate environmental, social and economical criteria.

ii) Quantitative: the classes are defined in common numerical terms; where comparison between the objectives is possible. Here considerable amount of economic criteria are used.

2.5 Soil-Evaluation Modeling

Within land evaluation, modeling is the fundamental component for the assessment of inherent soil quality. The models provide a tool for predicting the change in outcome caused by the changes in input parameters. By using land-evaluation models, it is possible to predict the rates and direction of many soil-quality changes. Land evaluation modeling focuses on different purposes which can be grouped in two main classes: land suitability or productivity, and land vulnerability or degradation approaches (De la Rosa *et al*., 2004).

The two principal land-evaluation modeling approaches are:

(i) empirical-based modeling, and (ii) process-based modeling.

The basic idea of empirical modeling for land evaluation is that observed relations are quantified and those analyzed (i.e. in a limited number of locations) are applicable for predicting future situations. However, this will not work unless there are sufficient data on which to base the inferences, so the methodology is not appropriate for new land uses or areas from which sufficient samples have not been taken. For land evaluations of established land uses with sufficient historical or experimental data, such analyses can be very useful and are often the preferred method (Van Lanen, 1991). This empirical-based modeling has moved on from simple qualitative approaches to other procedures that are more sophisticated and based on artificial intelligence techniques.

The linking of the land characteristics with land-use requirements or limitations may be as simple as making statements about land suitability for particular uses, or lands may be grouped subjectively into a small number of classes or grades of suitability. In many qualitative approaches, quantification is achieved by the application of the rule (that is, the minimum law) that the most-limiting land quality determines the degree of land suitability or vulnerability. This assumes knowledge of optimum land conditions and of the consequences of deviations from this optimum (Verheye, 1988).

Relatively simple systems of land evaluation depend largely on experience and intuitive judgment; they are really empirical models, and no quantitative expressions of either inputs or outputs are normally given. For instance, the Land Capability Classification System (USDA, 1961) and its many adaptations have been widely used around the world.

Parametric methods are considered a transitional phase between qualitative methods, based entirely on expert judgment, and mathematical models. They account for interactions between the most significant factors by the multiplication or addition of single-factor indexes. Multiplicative systems assign separate ratings to each of several land characteristics, and then take the product of all factor ratings as the final rating index. These systems have the advantage that any important factor controls the rating. The most widely known method to include specific, multiplicative criteria for rating land productivity inductively was developed by (Storie, 1989). In the additive systems, various land characteristics are assigned numerical values according to their inferred impact on land use. These numbers are either summed, or subtracted, from a maximum rating of 100 to derive a final rating index. Additive systems have the advantage of being able to incorporate information from more land characteristics than multiplicative systems. The FAO agro-climatic zoning project represents a milestone in the development of land evaluation, introducing a new approach to land-use systems analysis (FAO, 1978).

Expert systems as computer programs that simulate the problem-solving skills of human experts in a given field have been also used. They provide solutions to a problem, expressing inferential knowledge through the use of decision trees. In land evaluation, decision trees give a clear expression of the comparison between land-use requirements and land characteristics. The expert decision trees are based on scientific background and discussions with human experts, and thereby reflect available expert knowledge. Where suitable data on practical experience are available, statistical decision-tree analysis can be used to generate land-evaluation models with good prediction rates (De la Rosa and Van Diepen, 2003).

Neural networks, as an artificial intelligence technology, have grown rapidly over the past few years and have an ability to deal with nonlinear multivariate systems.

An artificial neural network is a computational mechanism that is able to acquire, represent, and compute a weighting or mapping from one multivariate space of information to another, given a set of data representing that mapping. It can identify patterns in input training data which may be missed by conventional statistical analysis. In contrast to regression models, neural networks do not require knowledge of the functional relationships between the input and the output variables.

Also these techniques are nonlinear and thus may handle complex data patterns that make simulation modeling unattainable (De la Rosa *et al.,* 1999).

The process-based models for land evaluation have been basically developed to simulate the growth of crops, along with associated phenomena that influence crop growth such as water and solute movement in soil. These simulation models are deterministic and based on an understanding of the actual mechanisms, but used to include a large empirical component in their descriptions of subsystems. The Wageningen models (e.g., *WOFOST* and *CGMS*) are based on soil processes and plant physiology to predict yields under several production levels (De la Rosa and Van Diepen, 2003).

Land evaluation methodologies have shifted from broad based to specific assessment, with increasing use of quantification (Elsheik *et al.,* 2010; Nwer, 2006). Significant amount of literature and research has been dedicated to intelligent systems for land use and management. Prominent land evaluation expert systems that have been developed and introduced in recent years are reviewed to enable comparative analysis. The land evaluation computer system (LECS) based upon the FAO framework for predicting local crop yields has been used to assess the land suitability for a variety of crops (Wood and Dent, 1983). However, the constraints of this system is simplicity (it is not interactive) and developed for areas in Sumatra (Nwer, 2006). EXGIS is a system integrating expert system shell designed for manipulating knowledge on land use suitability for agricultural purposes with GIS, a commercial computer package from ARC/INFO (Yialouris *et al*., 1997b). It is a rule based expert system for land and climate suitability evaluation in southern part of Greece. Five crops are considered maize, olive, tomato, wheat and grape.

ALES on the other hand is an automated land evaluation system that allows land evaluators to build expert systems for land evaluation according to the method presented in the Food and Agriculture Organization Framework for land evaluation (Johnson and

Cramb, 1991). This system offers the structure for a wide range of expert knowledge for a quick assessment, can be linked to socioeconomic evaluation, allow the evaluator's to build their own expert system, and has no fixed list for land characteristics or land use requirements. However, the implementation of the software does not seem to be very user-friendly and it is rather difficult for a non-IT-expert to make use of it. ALES is one of the few implementations with a knowledge-base based on FAO's Framework for Land Evaluation (FAO, 1976), therefore it should be considered as an alternative solution. (Rossiter, 1990; Rossiter and Wambeke, 1997).

The Micro-LEIS is an integrated system for land data transfer and agro-ecological land evaluation (Rosa *et al*., 1992, 2004, 2009). Currently, MicroLEIS have been integrated with GIS (Hoobler *et al.,* 2003). Hence, this system provides a computer-based set of tools for an orderly arrangement and practical interpretation of land resources and agricultural management data. Its major components include, land evaluation using the following spatial units: place (climate), soil (site-soil), land (climate site- soil), and field (climate-site-soil-management); data and knowledge engineering through the use of a variety of geo-referenced databases, computer programs, and boolean, statistical, expert system and neural network modeling techniques (Rosa *et al.,* 2004, 2009). The disadvantage of this system is that it does not allow the user to build a personal expert system (Nwer, 2006).

The Intelligent System for Land Evaluation (ISLE) is knowledge based, and models the evaluation of land in accordance with the FAO-SYS model for land evaluation. The system has as input a digital map of an area and its geographical database, displays this map, evaluates the land units selected by the user and finally visualizes the results of the land units in color (Tsoumakas and Vlahavas, 1999). The constraint of this system is that it does not support a wide range of problems in land evaluation.

Another system is LIMEX, which is an integrated expert system with multimedia that was developed to assist lime growers and extension agents in the cultivation of lime for the purpose of improving their yield (Mahmoud *et al.,* 1997). The scope of the LIMEX expert system includes assessment, irrigation, fertilization, and pest control. The expert system was augmented with multimedia capabilities by the integration of text, image, sound, video, and data which allows for a good feedback from users, assists in better understanding of the system, and allows for more flexibility in the interactive use of the system.

VEGES is another expert system developed for the diagnosis and treatment of pests, diseases and nutrient disorders of certain vegetable species (Yialouris *et al.,* 1997a). This system is simple and is based on forms of object-attribute-value (OAV) for the representation of symptoms. This method of representation easily fits into any rule based ES development tool, and thus is an advantage of the system.

Land evaluation using an Intelligent Geographical Information System (LEIGIS) is a software application resulting from research by Kalogirou (2002). LEIGIS was 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, and sugar beet) (Kalogirou, 2002). This system is limited to five crops and does not include characteristics such as climate. Model computer programs can also be implemented on the Internet through a web server, so that users can apply the models directly via a web browser. Jayasinghe and Machida (2008) developed an interactive web-based GIS online consulting system with crop-land suitability analysis, which provides information for tomato and cabbage cultivation. This system has the benefit of availability online, but is limited to two types of crop. There is a need for flexibility in the system with friendly user interface that allows the user to identify and change the requirements based on local conditions. Also the system should be able to accommodate new crops.

2.6 Fuzzy Decision Making

In land evaluation with fuzzy method, mainly bell-shape functions, such as sigmoid, cauchy and kandel functions were used. Fuzzy model has been used by many researchers in land suitability evaluation (Tang *et al.,* 1991; Van Ranst *et al.,* 1996; Keshavarzi and Sarmadian, 2009). Most of the researchers, have compared the results of this evaluation with other conventional methods such as maximum limitation, parametric and multiple regression methods in order to predicting the yield of production. Fritz and See (2005) studied the comparison of land cover maps using fuzzy agreement. The spatial fuzzy agreement between the two land cover products is provided. The results showed that fuzzy agreement can be used to improve the overall confidence in a land cover product. Sicat *et al.* (2005) used fuzzy modeling incorporating the farmers' knowledge to assign the weights of the membership functions. The final objective was to make land suitability maps for agriculture in Nizamabad district of Andhra Pradesh State in India. Tang *et al.* (1991) used fuzzy method for evaluation of Hamen lands in Liaoning province in China in order to cultivate corn. These researchers obtained the final matrix of suitability with constituting weight matrix and land characteristics matrix. Multiplication of the two were finally used to calculate the land index. In the study, multiple regression was used for the determination of weights. Sanchez (2007) while investigating land suitability for dry rice and rubber, used three methods including the investigation of land suitability using farmer's knowledge, land suitability classification with two-valued method using ALES model and evaluation based on fuzzy logic. AHP method was used for weighting in the study. The results of the study showed that obtained proportions from the three methods had differences in some cases. Also integration of farmer's knowledge with evaluation methods increased the correlation of evaluations with region conditions. The selection of appropriate membership function for land evaluation depends on the degree of characteristics changes in transition zone and boundary of classes. After the selection of membership function, determination of transition zone's width is one of the most important and critical stages of decision in fuzzy sets theory and accuracy of results is indebted in these decision.

The immediate question is why those researchers have tried to increase the complexity of the methodology by involving fuzzy theory and have not put effort towards the incorporation of more land characteristics in their empirical work.

Fuzzy theory works effectively with numerical data. However, it does not serve its aim to improve the quality of the classification since many of the variables used in the model have already had their values classified (such as many of the soil datasets are). It is argued here that research should focus on developing a more realistic model of land evaluation by incorporating more sources of data, such as geographical, climatological, socio-economic and cultural along with environmental and agro-ecological.

In different parts of Nigeria, researches on land suitability has been evaluated for various crops such as Cassava (Ande, 2011), Oil palm (Ogunkunle, 1993), Cocoa (Ogunlade *et al.,* 2012, Ibiremo *et al.,* 2010), maize and groundnut (Lemuel and Mwagim, 2014), cotton (Maniyunda *et al.,* 2001) However, there is no one that has combine two or more crops hence, this study was undertaken to evaluate soil suitability for some selected arable crops such as maize, cowpea, tomatoe and okro.

2.7 Decision Support Systems

A Decision Support System (DSS) is an interactive, flexible, and adaptable computer based information system that utilizes decision rules, models, and model base coupled with a comprehensive database and the decision maker's own insights, leading to specific, implementable decisions in solving problems that would not be amenable to management science models. Thus, a DSS supports complex decision making and increases its effectiveness (Tripathi, 2012).

In 1998, Turban defined a decision support system as "an interactive, flexible and adaptable system, exclusively designed to offer support in solving unstructured or semi-structured managerial problems, aiming to improve the decisional process. The system uses data (internal and external) and models, providing a simple and easy-to-use interface, thus, allowing the decision maker control over the decision process. The DSS offers support in all decision process's stages" (Turban, 1998) Some of the most important characteristics of the DSSs are: the use of data and models; enhancement of the learning process; growing efficiency of the decision making process; offering support in the decision making process and allowing the decision maker control over the entire process; offers support in all stages of the decision making process; offering support for decision makers in solving structured or unstructured problems; offering support for a user or for a group of users etc.

2.8 Decision Making and Models

Modeling simplifies reality and helps to conceptualize decision alternatives (Mallach 1994). Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system.

2.8.1 Benefits of modeling

The benefits or advantages of using modeling as stated by Turban *et al*., 2001 and Mallach, 1994 are:

i) The cost of modeling is much lower than the cost of experimentation conducted with a real system.

ii) Models allow for years of operation to be simulated in seconds of computer time.

iii) Manipulating the model is much easier than manipulating the real system: Experimentation is easier to conduct and does not interfere with the daily operation of the organization.

iv) The cost of making errors during trial-and-error experimentation is much lower when using models than the real system.

v) Modeling allows the calculation of risks in specific actions: Experimentation can be done in areas that involve considerable uncertainty.

vi) Mathematical models allow the analysis of solutions with very large or even an infinite number of alternatives.

vii) Models enhance and reinforce learning and support training.

viii) It is easier to access and manipulate a model when viewing alternatives than applying alternative options to the real world: Several decision options can be evaluated via computer models.

ix) It is easier to collect data from a computer model than from an actual system e.g. production bottlenecks: Data is easily collected as a by-product of a running model. In a real system, the data needs to be specially collected and recorded and

x) A model compresses time and yields results more quickly than the real world: That which takes years to achieve in the real world can be simulated and made available to decision makers in minutes.

2.8.2 Characteristics and capabilities of DSS

The characteristics and capabilities of DSS according to Turban (1995) are:

i. DSS support brings together human judgements and computerised information in a semistructured or unstructured situation. The problem cannot be solved by using a computerized system only.

ii. Support is provided for all levels of management.

iii. Support is provided to individuals as well as to groups. Less structured problems tend to require involvement of various individuals.

iv. DSS provide support to several interdependent and/or sequential decisions.

v. DSS supports all levels of decision-making: intelligence, design, choice and implementation.

vi. DSS supports a variety of decision-making processes and styles e.g. the individual’s decision style.

vii. DSS is adaptive over time. DSS should be able to adapt to changing conditions. Basic elements should be capable of being added, changed, combined, rearranged and adjusted to provide fast responses to unexpected situations.

viii. DSS is easy to use specially focussing on non-computer people. Users must feel ‘at home’ with the system. Ease of use implies an interactive mode.

ix. DSS attempts to improve effectiveness of decision-making including accuracy, timeliness and quality.

x. The decision-maker has complete control over all steps of the decision-making process. The system supports but does not replaces the decision-maker. The computer's recommendations can be overwritten at any time.

xi. DSS leads to learning and so initialises a process of developing and improving the DSS.

xii. DSS is relatively easy to construct. End users should be able to construct simple systems by themselves.

xiii. DSS usually utilises models. The modelling capabilities enable experimenting with different strategies under different configurations to provide new insights and learning. , and An advanced DSS is equipped with a knowledge component to solve difficult problems.

2.8.3 Benefits of a decision support system

Modelling is only one of the components of a DSS (Turban, 1995). Most companies use DSS to improve an aspect of their decision making operation. A DSS assists decision-makers to decide faster with less chance of error, thus improving the decision-maker's efficiency. The benefits most DSS provide as reported by (Turban, 1995; Mallach, 1994) are:

i) DSS have the ability to support the solutions of complex problems.

ii) DSS can expedite problem solving by providing information to decision-makers about similar decisions made in the past, thus providing increased consistency of similar decisions in the future.

iii) DSS provide fast responses to unexpected situations.

iv) DSS have the ability to try several different strategies under different configurations.

v) DSS provide new insight in learning or training. The ES component can be designed to provide this type of benefit. Most ES offer an interface that allows users to ask why the system made a particular recommendation and receive an answer in non-technical terms. Expert System users, after seeing many of these explanations, will understand the reasoning of experts in reaching the recommendation. Learning has then taken place, because these users would be able to make better decisions without the system.

vi) DSS facilitate communication: “What-if” analysis can be used to satisfy sceptics and improve teamwork.

vii) DSS facilitate interpersonal communication: One such way is as a tool of persuasion, using to illustrate a particular action to be taken in future, called offensive use, or using it to illustrate that a particular action was taken properly in the past, called defensive use. When viewed in a broader organisational context, these decisions could influence the group. GroupWare is a new form of DSS designed to accommodate the way a group reaches decisions, for instance using electronic mail or bulletin boards. There are also various other ways of electronic conferencing.

viii) Using DSS as a routine application can eliminate the cost of wrong decisions.

ix) DSS facilitate objective decisions by improving managerial effectiveness and allowing managers to perform a task in less time and/or with less effort. This results in more time for analysis, planning and implementation. , and

x) DSS increase organisational control: The DSS can constrain the individual’s decision to conform to organisational norms, guidelines or requirements. A level of consistency can be ensured across organisational units. An individual’s decisions could also be reported to his manager and then used to assess the productivity of the individual. This aspect has to be used very cautiously, because this might encourage the individual to make “safe” decisions not in the organisation’s best interest, or at the worst, damage morale. This use of DSS raises legal and ethical privacy issues.

2.8.4 Decision support system architecture

Figure 2.1 shows the fundamental component of a decision support system which are:

i. Data management subsystem

Data used by a DSS may be acquired from various sources which include: internal, external and personal sources (Turban, 1995) as well as from commercial databases and by collecting raw data (Turban *et al.,* 2001). Internal data refer to databases inside the company, some of them maintained by other information systems used by the company. External data refer to sources outside the company used around the globe that may range from commercial databases to data collected by sensors and satellites. If relevant, this data may interface with the DSS. In many DSS applications, data come from a data warehouse.

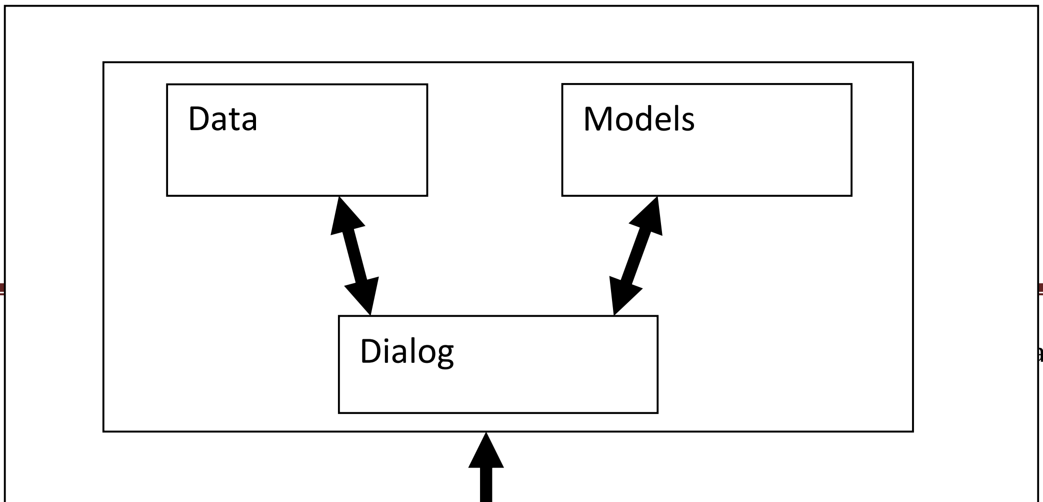


Figure 2.1: Basic Component of a Decision Support System (Sylvie and Camille, 1992)

A data warehouse includes DSS-relevant data extracted from different sources and organised as a relational database (Turban *et al*., 2001). Personal data refers to the users own expertise. This includes opinions for example what competitors are likely to do. Some external data flow to an organisation on a regular basis through electronic data interchange (EDI) or via other company-to-company data channels. Much data are also accessible via the internet in the form of home pages of vendors, clients and competitors. Information can be downloaded from these sites. Online publishers sell access to specialised databases, newspapers, magazines, bibliographies and reports in a timely manner and at a reasonable cost. Several thousand of these services are currently available. Raw data can be collected manually or by instruments and sensors. Regardless of how this data are collected, data need to be validated. The quality and integrity of the data are critical for a DSS. Therefore, safeguards on data quality are designed to prevent problems (Turban *et al.,* 2001).

Problems observed in large DSS include: incorrect data, untimely data, data not measured or indexed properly, too much data needed and non-existent of needed data. The data issue should be considered in the planning stage of the system life cycle of the DSS. If too many problems are anticipated, the system should not be undertaken. If the creation of the DSS involves the creation of a separate DSS database, the DSS builder will need to design and prepare the necessary data. Data may be organised using a relational, hierarchical, network or object orientated database model. Databases may be accessed via networks using technologies like client-server. Many companies develop enterprise-wide databases. Relational Database Management Systems (RDBMS) are better suited for DSS because their records do not contain predefined links to associated records in other files. This provides them with greater flexibility retrieving the data. Another advantage is the use of a standard interface called Structured Query Language (SQL). All major RDBMS vendors use SQL. It provides database connectivity (ODBC). ODBC is a programming interface that enables applications to access data in a DBMS that uses SQL as a data access standard.

ii. Dialogue subsystem or user interface

This subsystem is the key to successful use of the DSS. Various interface modes exist which determine how information is displayed and used. Dialogue styles, dialogue modes and conversation formats all contribute to the ease of use of the DSS. Styles such as menu interaction, command language, question and answer, form interaction, natural language and object manipulation are techniques used to assist the dialogue subsystem of a DSS. Graphics are especially important for problem solving, because it helps decision-makers visualise data, relationships and summaries.

Graphical User Interfaces (GUIs) are direct manipulation systems in which the user has direct control of the visible objects such as icons or buttons to replace complex command syntax. A wide variety of graphics such as: text - in the form of titles and descriptions, time-series charts, bar and pie charts, scatter diagrams - showing the relationship between two variables, two- or three-dimensional maps, room layouts, hierarchy charts, sequence charts, motion graphics and desktop publishing are all viable options when designing user interfaces. A subset of the above options can be used to enhance the specific DSS, whether the DSS produces reports or just visualize problems and potential solutions.

User interfaces can be enriched by the use of interactive multimedia. One new class of multimedia is called hypermedia and includes several types of media such as text, graphics, audio and video elements as tools to navigate knowledge and data and capture results. Associated knowledge can be linked with hypertext allowing the user to control navigation to various components. Virtual reality, presenting a 3-D user interface, offers rich opportunities for powerful interactions. The implementation of 3-D is difficult and expensive. In virtual reality, a person "believes that what he or she is doing is real", even though it is artificially created (Turban *et al.,* 2001).

The dialogue subsystem serves to integrate various other subsystems as well as to be responsible for user-friendly communications between the DSS and the decision maker. The subsystem coordinates all functions or commands selected by the decision maker. The interface provides flexibility for customizing the system by the decision maker, the interface is designed so that the decision maker can create, modify or eliminate criteria, or even define which criteria he/she intends to inquire about. A decision maker utilizes the database through the dialogue subsystem for analyzing different alternatives using the knowledge management subsystem.

iii. Model or Knowledge management subsystem

An important characteristic of DSS is the inclusion of a modeling capability (Turban, 1995). The DSS analysis is executed on a model of reality, rather than reality itself. As stated before, a model is a simplified representation or abstraction of reality, which has advantages such as lower cost of experimentation, compression of time, manipulation of the model itself, lower cost of error, reinforcement of learning and enhanced training. It is limiting to take reality to mean that which presently exist. Some DSS tools exist to explore situations that do not yet exist. To include such tools as models, reality should include that which could come about in future (Finlay, 1994).

2.8.5 DSS models

According to Mallach (1994), DSS uses the fourth type of model: a symbolic or mathematical model also called an information-based model. Reality is represented by data, which can be processed or interpreted as information. The data elements used in this model normally consists of values containing True/False, character strings or numerical values - any type that computers and computer programs can deal with. The symbolic model incorporates procedures and formulas to manipulate the model's data elements. The values of new data elements are derived. The model may use external values received from the database, the user or other information systems.

In DSS, models are used to predict the outcome of decision choices made (Mallach, 1994). DSS represent reality by information about reality. A DSS can incorporate several different types of mathematical models. The DSS builder is often faced with the dilemma of which models to include in the DSS and whether to build new models, to use ready-made ones or to modify existing models. Until recently, mathematical modelling formed the core of almost all DSS. Many applications nowadays use logical relationships other than mathematical ones as the basis of their DSS. Mathematical-based DSS however still constitute the majority of applications (Finlay, 1994; Turban *et al*., 2001). A tendency exists to complement mathematical modelling using computer graphics in Decision Support Systems.

2.9 Fuzzy Set Classification in Land Suitability

One problem with the traditional approaches to land suitability analysis is that they do not assure a spatial pattern with contiguity or compactness in land allocations for different land use types. A central and critical issue of methodology in land suitability evaluation is how to parameterize and combine land attributes of a different nature in order to model the productive response of target species to a given set of environmental factors. Geo-spatial data consisting of discrete, sharply hounded units is incapable of representing the reality: the continuous nature of variability of environmental factors and their small-scale spatial heterogeneity. Moreover, considerable details may occur when data classified according to such a rigid-data model are retrieved or combined using Boolean methods (Malczewski, 2004; Corona *et al.,* 2008). The fuzzy set theory offers a useful alternative in this respect; it permits the gradual assessment of the membership of elements in a set with the aid of a continuous scale of membership (Burrough and McDonnell, 1998), the membership function, valued in the real unit interval [0,1] on the Boolean scale and [0, 255] on the byte scale . The fuzzy set classification allows transition from one class to another to be described by means of a membership function. In the application of land suitability evaluation, the use of a fuzzy set classification is particularly helpful to model the productive response of the target species to single environmental factors. This can be better expressed as a gradual transition (soft classification), rather than abrupt shifts from one class to another (hard classification). Such a gradual transition can be quantified according to fuzzy membership functions valued in the interval [0, 1] or [0, 255], where 1 or 255 means a complete suitability (the environmental factor matches the ecological requirements of the target species: the optimum of the species) and 0 means no suitability (Corona *et al.,* 2008). The appropriate fuzzy membership function is dependent on the best available knowledge of the target species' ecological requirements, as drawn from literature and field, knowledge (Eastman, 2006). Although the fuzzy logic approach to land-use suitability modeling is shown to have fewer limitations than conventional techniques, the approach is not without problems. The main difficulty associated with applying the fuzzy logic approach to land suitability modeling is the lack of a definite method for determining the membership function (Malczewski, 2004).

2.10 Fuzzy Logic

Fuzzy logic is a convenient way to map an input space to an output space. This is the starting point for everything else, and the great emphasis here is on the word “convenient “(Matlab, 2002). The following is a list of general observations about fuzzy logic (Matlab, 2002):

i. Fuzzy logic is conceptually easy to understand. The mathematical concepts behind fuzzy reasoning are very simple. What makes fuzzy nice is the “naturalness “of its approach and not it’s far – reaching complexity.

ii. Fuzzy logic is flexible. With any given system. It’s easy to manage it or layer more functionality on top of it without starting again from scratch

iii. Fuzzy logic is tolerant of imprecise data. Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.

iv. Fuzzy logic can model nonlinear function of arbitrary complexity. You can create fuzzy system to match any set of input – output data. This process is made particularly easy with adaptive techniques like ANFIS (Adaptive Neuro – Fuzzy Inference Systems), which are available in the fuzzy Logic Toolbox.

v. Fuzzy logic can be built on top of experience of experts. In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you rely on the experience of people who already understand your system

vi. Fuzzy logic can be blended with conventional control techniques. A fuzzy system does not necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.

vii. Fuzzy logic is based on natural language. The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic.

The fuzzy system is a popular computing framework based on the concepts of “fuzzy set theory”, “fuzzy if then rules” and fuzzy reasoning”. The structure of fuzzy inference consists of three conceptual components (Karady, 2001), namely: Rule Base containing a selection of fuzzy rules, database that defines the membership functions. These are used in the fuzzy rules and the reasoning mechanism performs the inference procedure upon the rules and given facts and derives a reasonable output or conclusion.

Sometimes it is necessary to have a crisp output (Matlab, 2009). This requires a method called De - fuzzification, to extract a crisp value that best represents the fuzzy output. With such crisp inputs and outputs, a fuzzy expert system implements a non-linear mapping from the input space to the output space. Mapping is accomplished by a number of if – then rules, each of which describes a local behavior of the mapping. There are four basic membership functions namely triangular, trapezoidal, Gaussian and generalized bell (Karady, 2001). The different types of membership functions are represented in Figure 2.2.

2.10.1 Fuzzy logic system

Fuzzy logic is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical predicate logic. It can be thought of as the application side of fuzzy set theory dealing with well thought out real world expert values for a complex problem (Klir *et al.*,1977). Fuzzy logic allows for membership values to range (inclusively) between 0 and 1, and in its linguistic form, imprecise concepts like "slightly", "quite" and "very". Specifically, it allows partial membership in a set. It is related to fuzzy sets and possibility theory. It was introduced in 1965 by Lofti Zadeh at the University of California, Berkeley.

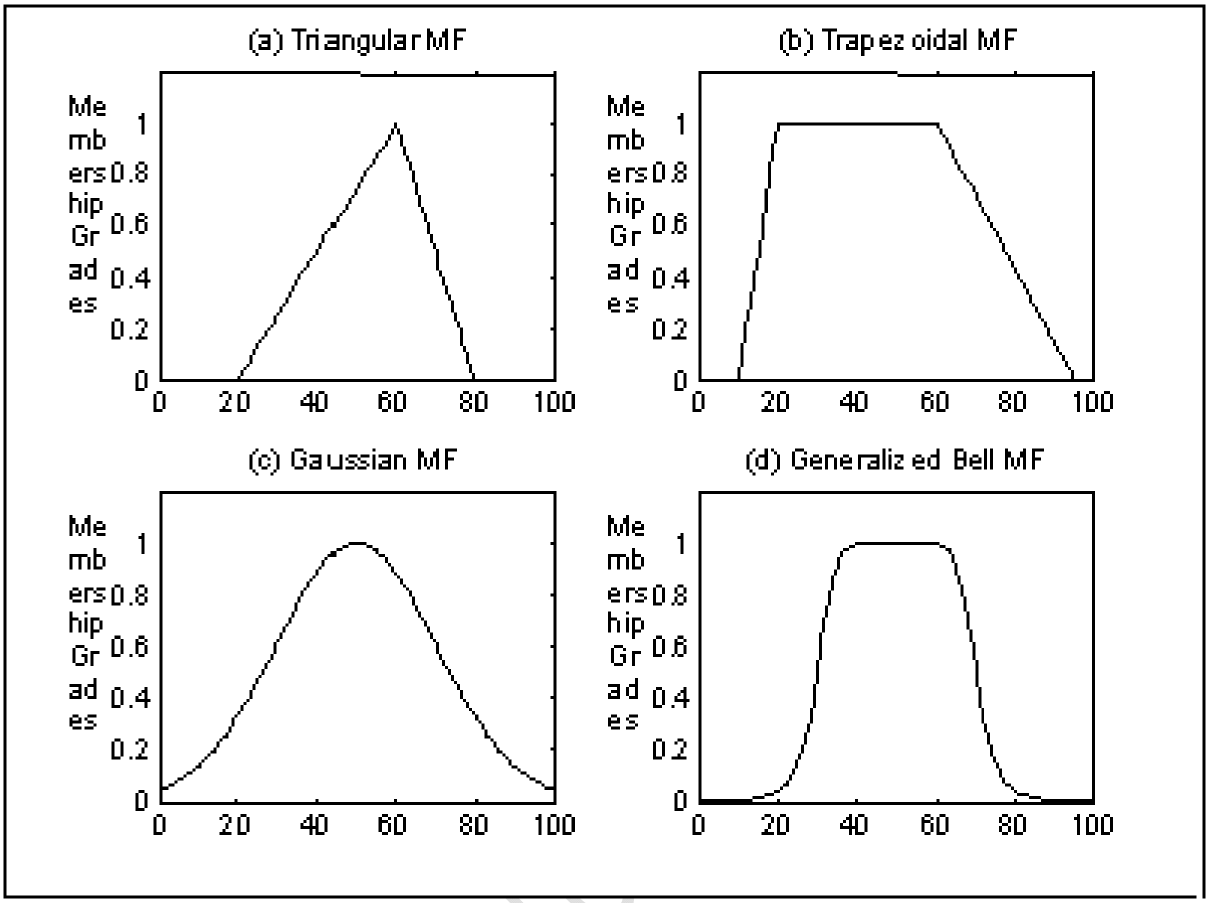


Figure 2.2: Types of Membership Functions (Source: Karady, 2001)

2.10.2 Problems associated with fuzzy systems

There are some basic problems in the design of a fuzzy system (Godjevac, 1993) and they are:

i. There is no standard method for the transformation of the human knowledge or experience into the rule base of a fuzzy inference system, no general procedure for choosing the optimal number of rules, since a large number of factors are involved in the decision, e.g. performance of the controller, efficiency of computation, human operator behavior, the choice of linguistic variables, etc.

ii. Even when human operators exist, their knowledge is often incomplete and episodic,

iii. There is a need for a good method for tuning the membership functions in order to minimize the output error measure or maximize a performance index.

2.10.3 Essential characteristics of fuzzy logic

Some of the essential characteristics of fuzzy logic relate to the following (Machado and Rocha, 1992) in Full´er (1995):

i. In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning.

ii. In fuzzy logic, everything is a matter of degree.

iii. In fuzzy logic, knowledge is interpreted as a collection of elastic

iv. Inference is viewed as a process of propagation of elastic constraints.

v. Any logical system can be fuzzified.

There are two main characteristics of fuzzy systems that give them better performance for specific applications.

i. Fuzzy systems are suitable for uncertain or approximate reasoning, especially for the system with a mathematical model that is difficult to derive.

ii. Fuzzy logic allows decision making with estimated values under incomplete or uncertain information.

2.10.4 Fuzzy set

A fuzzy set is a class of object with a continuum of grades of membership (Zadeh, 1965). Such a set is characterized by a membership (characteristic) function which assign to each object a grade of membership ranging between zero and one. The notions of inclusion, union, intersection, complement, relation, etc., are extended to such sets, and various properties of these notions in the context of fuzzy sets are established. Fuzzy sets are sets whose elements have degrees of membership. The concept of Fuzzy set was introduced in Zadeh (1965) as a means of representing and manipulating data that was not precise, but rather fuzzy. There is a strong relationship between Boolean logic and the concept of a subset, there is a similar strong relationship between fuzzy logic (FL) and fuzzy subset theory (Full'er, 2000).

In classical set theory, a subset A of a set X can be defined by its characteristic function μA as a mapping from the elements of X to the elements of the set 0, 1,

Similarly, a fuzzy subset A of a set X can be defined as a set of ordered pairs, each with the first element from X, and the second element from the interval [0, 1], with exactly one ordered pair present for each element of X. This defines a mapping, A, between elements of the set X and values in the interval [0, 1]. The value zero is used to represent complete non-membership, the value one is used to represent complete membership, and values in between are used to represent intermediate degrees of membership. The set X is referred to as the universe of discourse for the fuzzy subset A. Frequently, the mapping μA is described as a function, the membership function of A. The degree to which the statement "x is in A" is true is determined by finding the ordered pair $(x, \mu A (x))$. The degree of truth of the statement is the second element of the ordered pair (Fuller, 2000).

2.10.5 Linguistic variables

A linguistic variable is characterized by a quintuple (X,T,U,G,M) where X is the name of the variable, T is the set of terms of X, U is the universe of discourse, G is a syntactic rule for generating the name of the terms, and M is a semantic rule for associating each term with its meaning, that is, a fuzzy set defined on U.

Fuzzy sets can be used to represent linguistic variables. Linguistic variables represent the process states and control variables. Their values are defined in linguistic terms. For example, for the linguistic variable: temperature, we can define a set of terms: T(temperature) = negative big, negative medium, negative small, close to zero, positive small, positive medium, positive big (Godjevac, 1993).

2.10.6 Fuzzy rules

IF-THEN rules offer a convenient format for expressing pieces of knowledge. But it is just a format which can cover different intended semantics and uses. The "consequent" of a rule may be qualified with various modalities expressing for instance, strong ones such as certainty, obligation, or weaker ones such as possibility or feasibility. Rules may have implicit exceptions, or may universally hold. Depending on their interpretation, rules have to be represented and processed in a specific way at the inference level. Strangely enough, in spite of the acknowledged importance of fuzzy rules and of the great number of works in fuzzy set based approximate reasoning, there has been very little concern until now about the possible intended meanings of a fuzzy rule, although fuzzy rules seem to play an important role in our thinking mechanisms (Dubois and Prade, 1996).

2.10.7 Structure of fuzzy inference system

The fuzzy inference system is a popular computing framework based on the concept of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. Figure 2.3 is a sketch of the structure of fuzzy system. It is composed of four principal blocks (Godjevac, 1993):

1. Knowledge base (rules and parameters for membership functions)
2. Decision unit (inference operations on the rules)
3. Fuzzification interface (transformation of the crisp inputs into degrees of match with linguistic variables)
4. Defuzzification interface (transformation of the fuzzy result of the inference into a crisp output)

The FUZZY part of the system in Figure 2.3 is represented on the Figure 2.4.

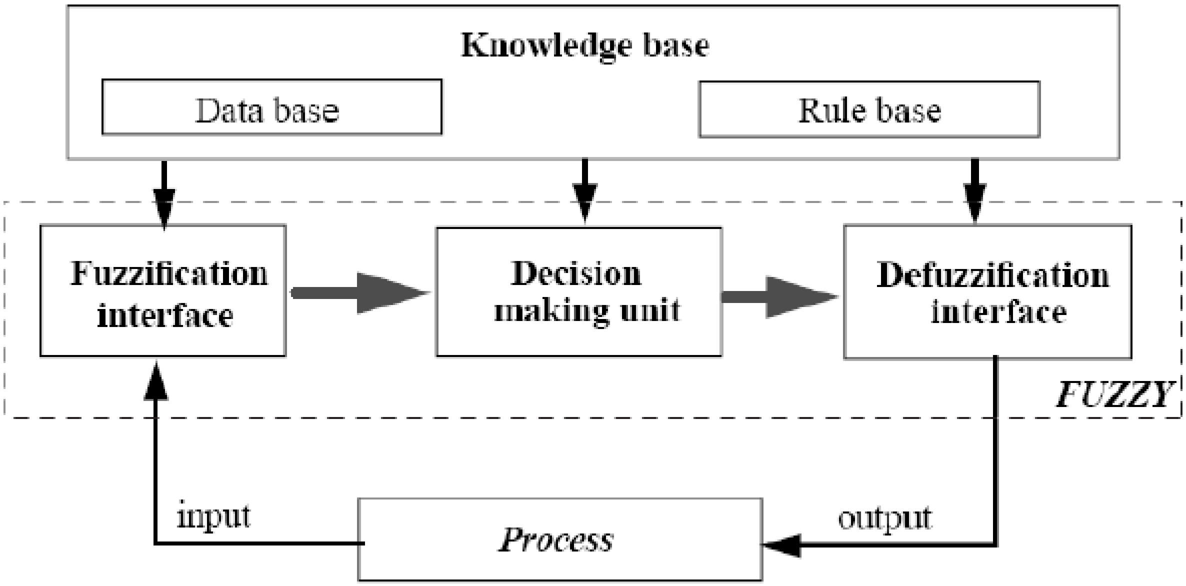


Figure 2.3: Structure of Fuzzy Inference System (Godjevac, 1993).

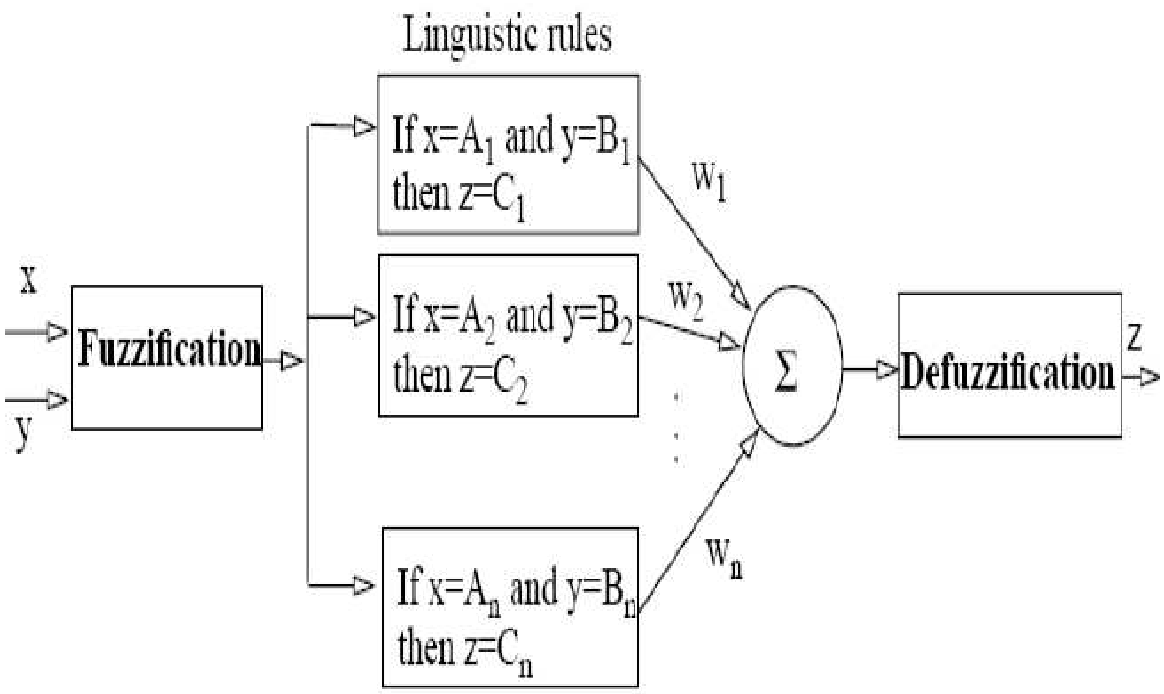


Figure 2.4: Structure of the FUZZY Part of the System (Godjevac, 1993)

CHAPTER THREE

METHODOLOGY

3.1 Introduction

In this chapter, various methods and techniques used to achieve the set objectives of the work are described in detail. The architecture of the propose system was described, the model of the work is described as well as the data used for the model. The general overview of the entire architecture of the decision support system is presented in Figure 3.1. The architecture of the system is composed of three main blocks which are:

3.1.1 The knowledge management subsystem or fuzzy inference engine

This component is essentially the brain of the knowledge based system that provides methodology for reasoning on information in the knowledge base and the working memory for formulating conclusion. The reasoning mechanism takes place in the inference engine according to the facts received from the user interface. The knowledge management subsystem manages all the fuzzy methods available in the DSS. For the sake of describing the proposed DSS, fuzzy methods have been included in the proposed DSS to assist the decision maker select the most appropriate crop to be planted. There are different selection for the fuzzy inference engine depending on the aggregation, implication and operators used for s-norm and t-norms (Li-Xin Wang, 1994).

3.1.2 The dialog subsystem or user interface

The dialogue subsystem serves to integrate other subsystems as well as to be responsible for user-friendly communications between the DSS and the decision maker. The

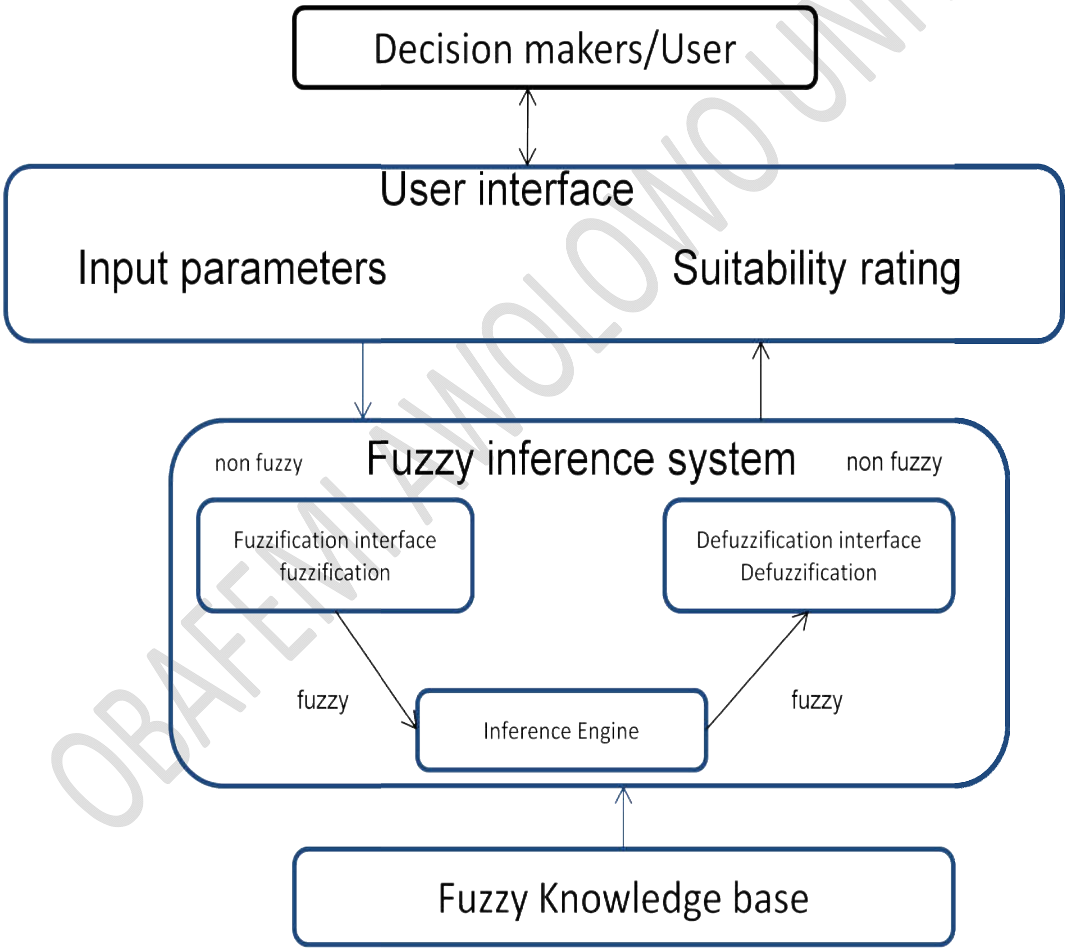

Decision makers/User
User interface
Input parameters
Suitability rating
non fuzzy
Fuzzy inference system
non fuzzy
Fuzzification interface
fuzzification
Defuzzification interface
Defuzzification
fuzzy
Inference Engine
fuzzy
Fuzzy Knowledge base

Figure 3.1: Architecture of Fuzzy Decision Support System for Soil Suitability Evaluation.

subsystem coordinates all functions or commands selected by the decision maker. The interface provides flexibility for customizing the system by the decision maker, the interface is designed so that the decision maker can create, modify or eliminate criteria. A decision maker utilizes the database through the dialogue subsystem for analyzing different alternatives using the knowledge management subsystem. Users of this system are agriculture experts that enter the real number of all variables via user interface. Also, user interface shows the suitability rating.

3.1.3 Fuzzy rule base

Experts' experience is used to build up the fuzzy rules. These rules are conditional statements and can be represented as "IF x is Xi and y is Yi and … THEN o is Oi" Where x and y are linguistic input variables. Xi and Yi are possible linguistic values for x and y; respectively.

3.2 Knowledge Acquisition or Data Collection

Knowledge acquisition plays a crucial role for the development of a reliable DSS and requires the close collaboration of the knowledge engineer with the domain experts. For the development of the system a knowledge acquisition procedure consisting of the following four stages were followed:

Domain Acquaintance: This stage aimed at the acquaintance of the knowledge engineer with the application domain. To this end, books and papers related to soil and land evaluation issues was studied and reviewed.

Meetings with the Experts: This stage aimed at the development of an understanding of the experts' way of thinking. At the same time, effort was made to elicit the experts' opinion for the DS's contribution to soil evaluation procedure. To this end, two meetings were organised with an agronomist and soil scientists. After the second meeting, the experts were asked to propose:

i. The plants which should be considered for the development of the DS.
ii. The soil and climatic requirements which are important for each cultivation.
iii. The potential evaluation classes into which the soil could be classified.

In response, the experts proposed four crops for cultivation: Maize, Cowpea, Tomato, and Okro. Crop requirement data are classified in accordance with land suitability classes: Class S1 (*Highly Suitable*), Class S2 (*Moderately Suitable*), Class S3 (*Marginally Suitable*), Class N1 (*Currently not Suitable*) and Class N2 (*Permanently not Suitable*). The order and description of the classes are shown in Table 3.1.

3.3 Analysis of the System using UML

On the surface, UML is a visual language for capturing software designs and patterns. It can be applied to a large number of different areas and can capture and communicate everything from company organization to business processes to distributed enterprise software. It is intended to be a common way of capturing and expressing relationships, behaviours, and high-level ideas in a notation that's easy to learn and efficient to write. UML is visual; just about everything in it has a graphical representation (Pilone and Pitman, 2005).

First and foremost, it is important to understand that UML is a language. This means it has both syntax and semantics (Pilone and Pitman, 2005). UML provides a way to capture and discuss requirements at the requirements level, sometimes a novel concept for developers. There are diagrams to capture what part of the software realize certain requirements. Also, there are diagrams to capture exactly how those parts of the system realize their requirements. Finally there are diagrams to show how things fits together and executes

Table 3.1: Land Suitability Classes (FAO, 1976)

	Class	Description
Suitable	S1(Highly suitable)	Land having no, or insignificant limitations to the given type of use
	S2 (Moderately suitable)	Land having minor limitations to the given type of use
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use

Not suitable	N1(Currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2(Permanently not suitable)	Land that have so severe limitations that are very difficult to be overcome

(Miles and Hamilton, 2006).

Obviously the focus of UML is modelling. It is a means to capture ideas, relationships, decisions, and requirements in a well-defined notation that can be applied to many different domains. Modelling not only means different things to different people, but also it can use different pieces of UML depending on what you are trying to convey. The static structure, or class diagram, depicts the time-independent relations between the objects in the model. Classes are collections of objects. In this case, the model applies to a soil suitability evaluation system. Although, it is common to omit attributes and relations in a conceptual model, some of them were added here to clarify the model structure (Figure 3.2), including attributes allows to easily check the consistency of the conceptual model; if attributes are not included it is easier to define overlapping or inaccurately defined classes. The static structure diagram shows how information in the system at hand is related. It clarifies which properties are inherited, and it indicates how the different objects relate to each other. Thinking about accurate classes and subclasses provides a better insight into the system and provides a sound basis for model implementation. Moreover, it leads to a modular structure, which makes it easier to attach new functions or indicators.

Figure 3.3 shows the activity diagram of the system. Activity diagrams are used during the design phase of complex methods. Alternately, the activity diagram can also be used during analysis to break down the complex flow of a use case. Through an activity diagram, the designer/analyst specifies the essential sequencing rules, the method or use case has to follow. UML activity diagrams are an updated and enhanced form of flowcharts; the main enhancement over flowcharts is the ability to handle parallelism, as will be discussed. An activity diagram is a variation of a state chart in which the states are activities representing the performance of operations and the transitions are triggered by the unconditional

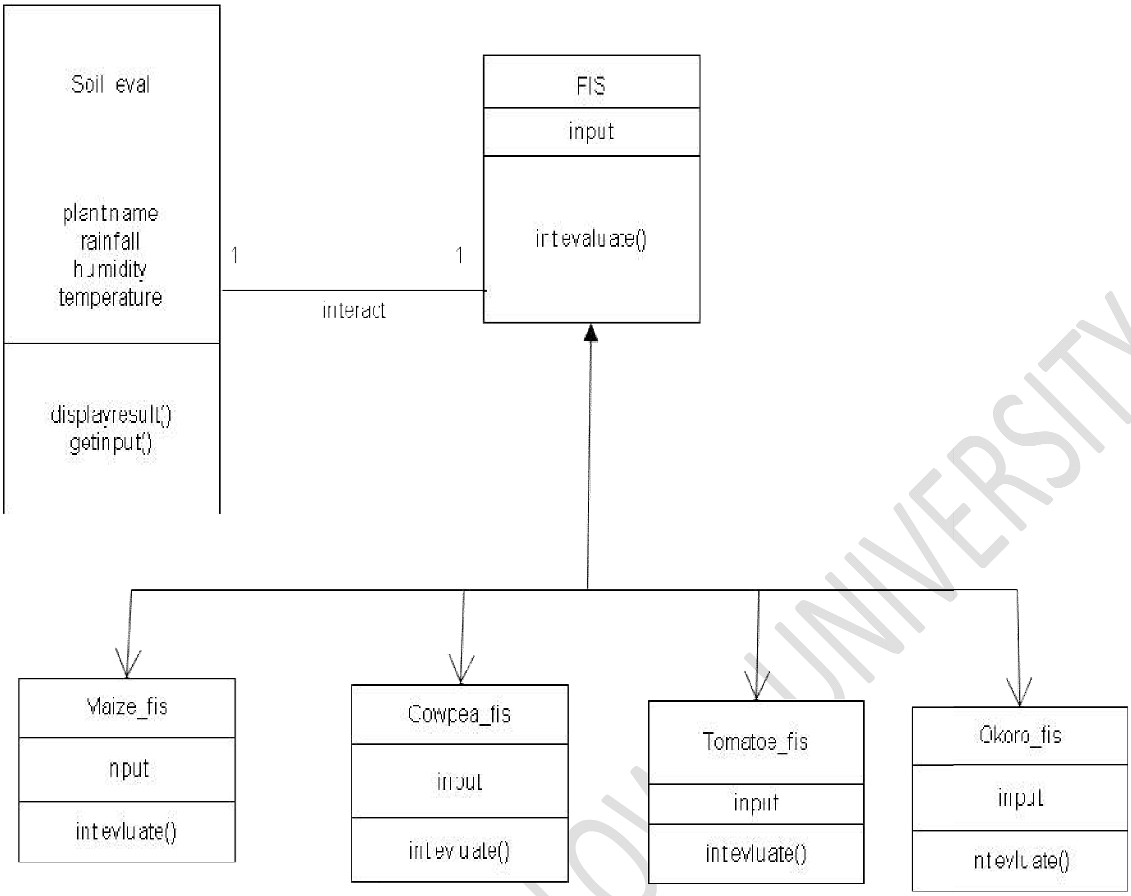


Figure 3.2: Class Diagram of the Suitability Evaluation System

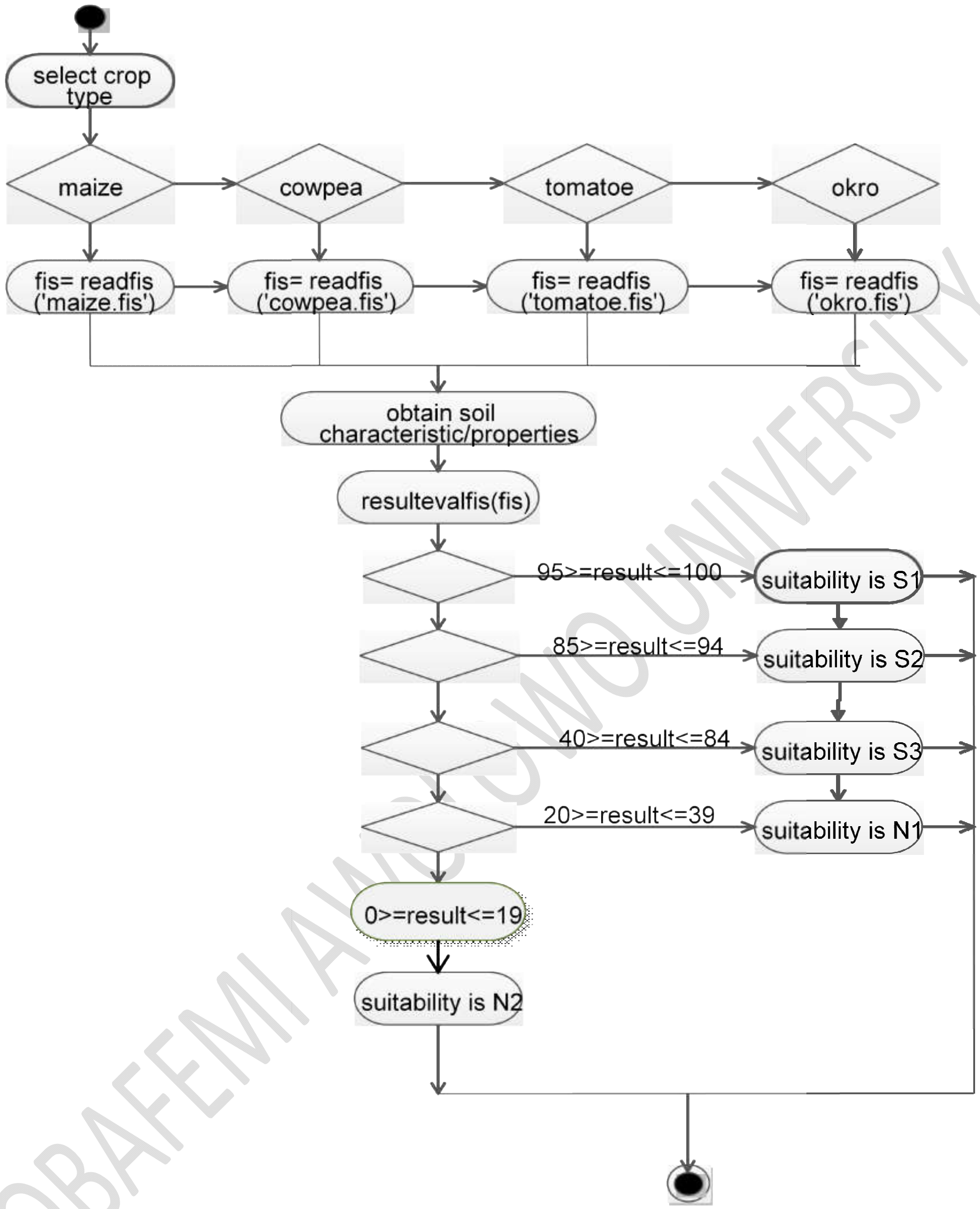


Figure 3.3: Activity Diagram

Completion of the operations. An activity is a single step that needs to be done, whether by a human or a computer (Fowler, 2000). Incoming transitions (an incoming arrow) trigger the activity. If there are several incoming transitions, any of these can trigger the activity independent of the others (Oestereich, 2001).

3.4 Design of the Fuzzy Decision Support System

The goal of a fuzzy DSS is to take in subjective, partially true facts randomly distributed over a sample space, and build a knowledge-based system to produce useful decisions (Vadiee, 1994). The overview of the framework is shown in Figure 3.4. There are 7 fundamental Steps in the development of a fuzzy DSS. Details of these steps are as follows:

3.4.1 Identification and analysis of the problem

The problem of selecting the correct land for the cultivation of a certain agriculture product is a long-standing and mainly empirical issue. Although many researchers, organizations, institutes and governments have tried to provide a framework for optimal agricultural land use, it is suspected that much agricultural land is used at below its optimal capability. The increased need for food production and the shortage of resources stimulate a need for sophisticated methods of land evaluation to aid decision makers in their role to both preserve highly suitable lands and satisfy producers' demand for increased profit. The immediate question is why those researchers have tried to increase the complexity of the methodology by involving fuzzy theory and have not put effort towards the incorporation of more land characteristics in their empirical work?

3.4.2 Identification of critical factors and membership functions

This step involves the compilation of a list of critical factors based on a literature review and in depth interviews with Experts (Agronomist and Soil Scientist). From this interaction it was

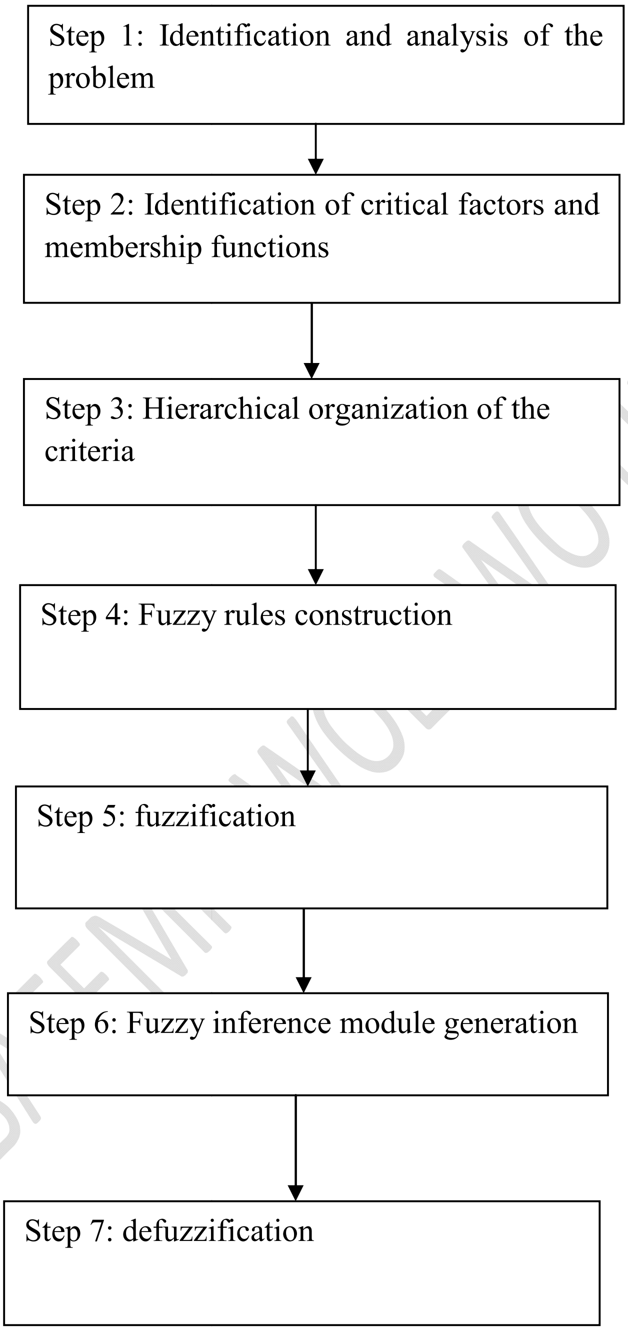


Figure 3.4: Fuzzy Inference Process for Land Suitability Evaluation

discussed that there are fourteen influencing factors contributing primarily to a decision making and typical land suitability decisions. These are rainfall, length of dry season, temperature, humidity, slope, flooding, drainage, texture, coarse fragment, depth, Cation exchange capacity, base saturation, pH, and Organic carbon. The most important task in the process of designing a fuzzy logic decision support system is the identification of influencing parameters and to their relation on decision making process. Land characteristics are selected as shown in Table 3.2 in accordance to the limitations being used. In this study, limitations were grouped into five different sets: climate, topography, wetness, soil physical properties and fertility. Data on crop growth requirements were obtained from experts, researches and land mapping activities which have been previously done by various researchers and practitioners in land suitability. In a land suitability decision-making system, the land factors contributing primarily to a decision making and the typical land suitability decisions are the fuzzy variables. After discussions with experts in the field of land suitability decision-making, fourteen influencing factors and five typical decisions were determined. The following evaluation criteria are considered to address the land suitability decision making.

1. Climate

    a. Rainfall

    b. Length of dry season

c. Temperature

d. Relative humidity

2. Topography

a. Slope

Table 3.2: Limitations and Land Characteristics being Used

Limitations	Land Characteristics
Climate	Annual rainfall, Length of dry season, Temperature, Relative humidity
Topography	Slope
Wetness	Flooding, Drainage
Soil physical properties	Texture, Structure, Coarse fragments
Soil fertility	Cation exchange capacity, Base saturation, PH, Organic carbon.

3. Wetness

   a. Flooding

   b. Drainage

4. Soil Physical Characteristics

   a. Texture

   b. Coarse fragment

   c. Depth

5. Fertility

   a. pH

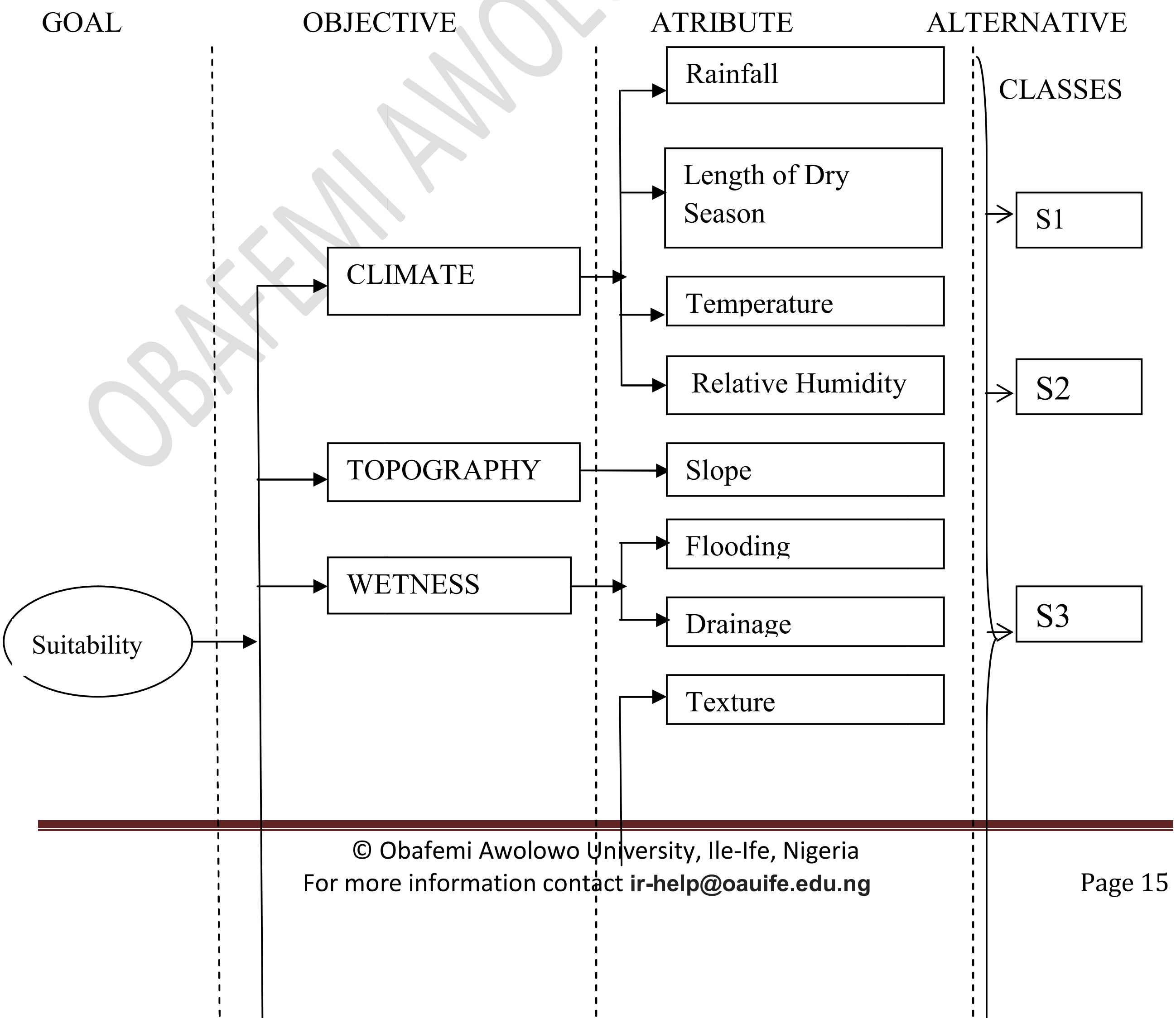
   b. Organic carbon (OC)

   c. Base Saturation

   d. Cation Exchange Capacity (CEC)

3.4.4 Hierarchical organisation of the criteria

Malczewiski (1999) states that relationship between the objective and the attributes has a hierarchical structure. At the highest level one can distinguish the objectives and at lower levels, the attributes can be decomposed. Figure 3.5 shows the hierarchical structure used in this study. Hierarchical organization of the criteria is common in large decision problems. This is advantageous in the decision making process. Where relative importance of the criteria under evaluation is to be establish consciously. It is proven that the human brain is not able to process more than seven stimuli at a time (Miller, 1956). Besides empirical studies showed that people cannot compare more than three criteria at the same time



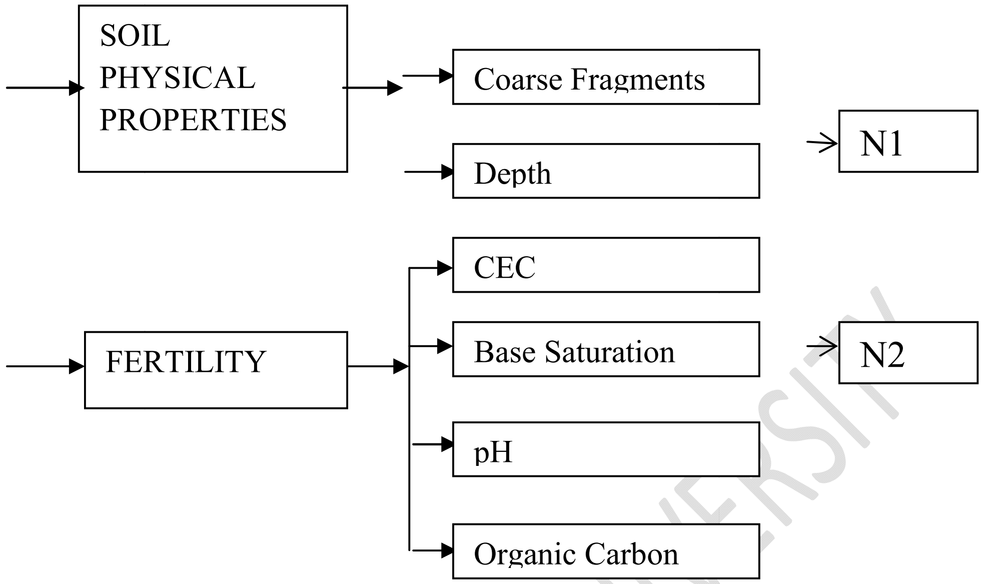


Figure 3.5: Hierarchical Organization of the Criteria used in this Study

(Rommelfanger,2003). Therefore, a hierarchical organization of the criteria helps to decompose the complex decision making process, as suitability evaluation.

3.4.4 Fuzzy rule construction

The heart of fuzzy based system is knowledge base consisting of so-called fuzzy IF….rules. A fuzzy if then rule is an if then statement in which some words are characterized by continuous membership functions (Smith, 1992; Wang, 1997). Fuzzy DSS makes decisions and generate output values based on knowledge provided by the designer in the form of IF _condition_ THEN action_ rules. The rule base specifies qualitatively how the output parameter "suitability rating" of the land proposal is determined for various instances of the input parameters of "temperature", "rainfall" and "length of dry season", "relative humidity", "slope", “flooding”, “drainage”, “texture”, “coarse fragment”, “depth”, “CEC”, “base saturation”, “pH”. An example of fuzzy rules modeling land suitability for average temperature, rainfall and relative humidity is shown in Figure 3.6. A total of 59 *IF-THEN* rules were used to build the rule-based structure for the proposed suitability evaluation fuzzy system. Figure 3.7 shows a selection of these rules.

3.4.5 Fuzzification

After identifying all parameters (input and outputs) needed for building our fuzzy model, fuzzifying those parameters was the next stage. For each of those parameters, appropriate linguistic variables associated with their numerical ranges have been specified using experts’ knowledge in agric as well as analysis of crop data from previous years. For example, Table 3.3 shows the linguistic variables and their numerical ranges for rainfall factor. Linear triangular membership functions was used to design the fuzzy sets for all linguistic variables. Figure 3.8 shows two examples of fuzzified parameters. Fuzzification

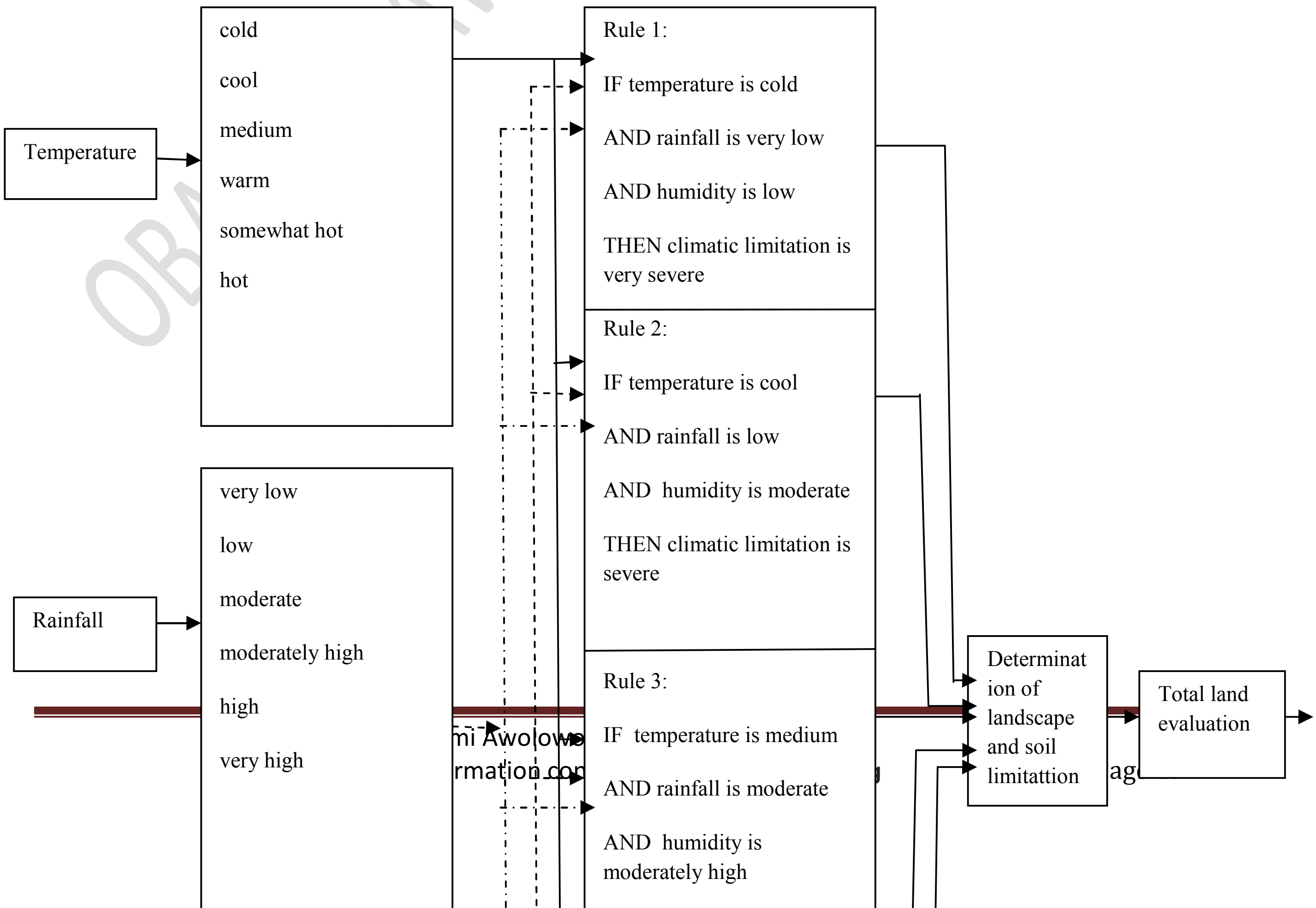


Figure 3.6: Fuzzy Rules Modeling Land Suitability for Temperature, Rainfall and Humidity

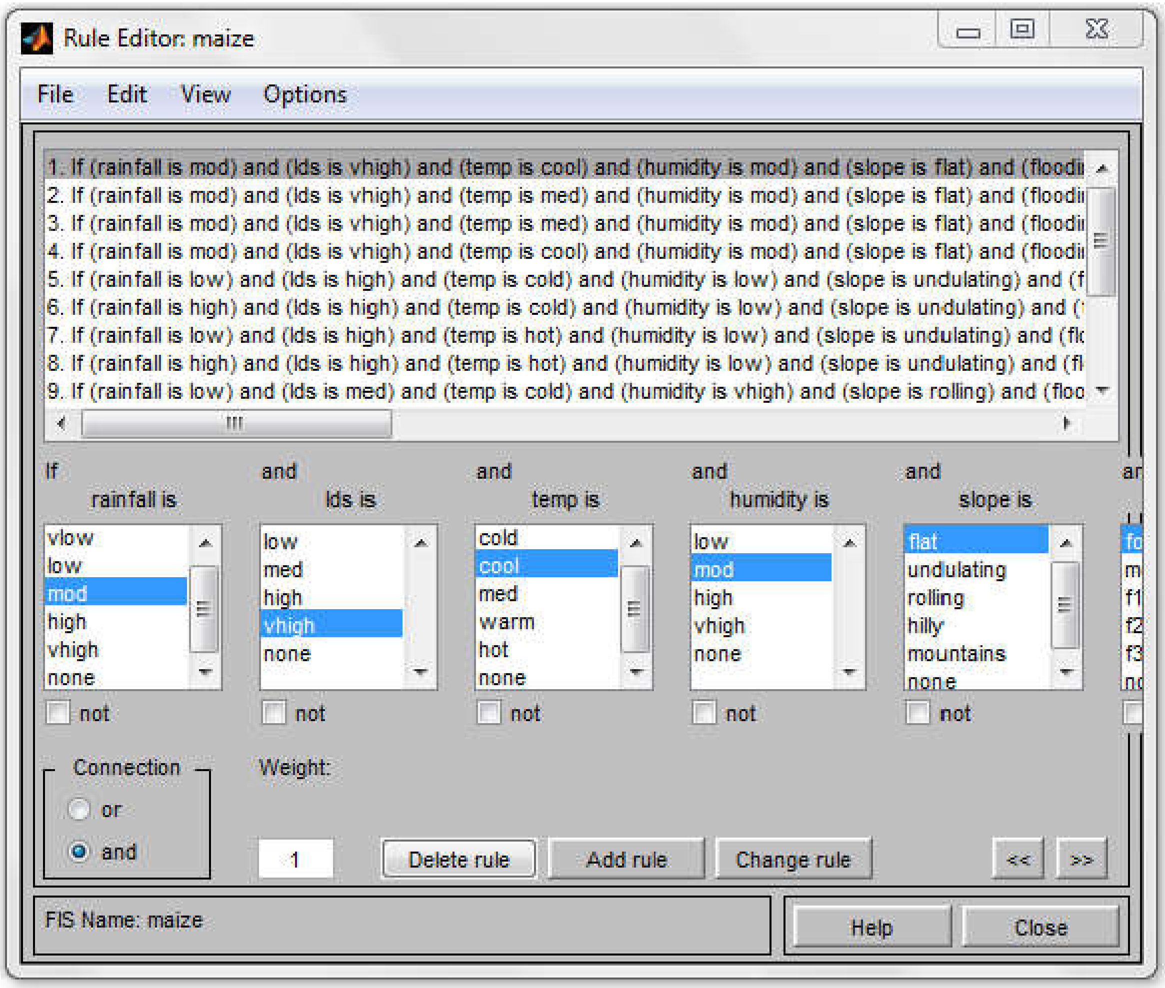


Figure 3.7: Screen Capture of the Rule Editor for Maize Crop

Table 3.3: Linguistic Variables and their Ranges for Rainfall

Linguistic value	Numerical range (per annum)
Very low	0-600
Low	600-900
Moderate	800-1300
High	1200-1800
Very high	1600-2200

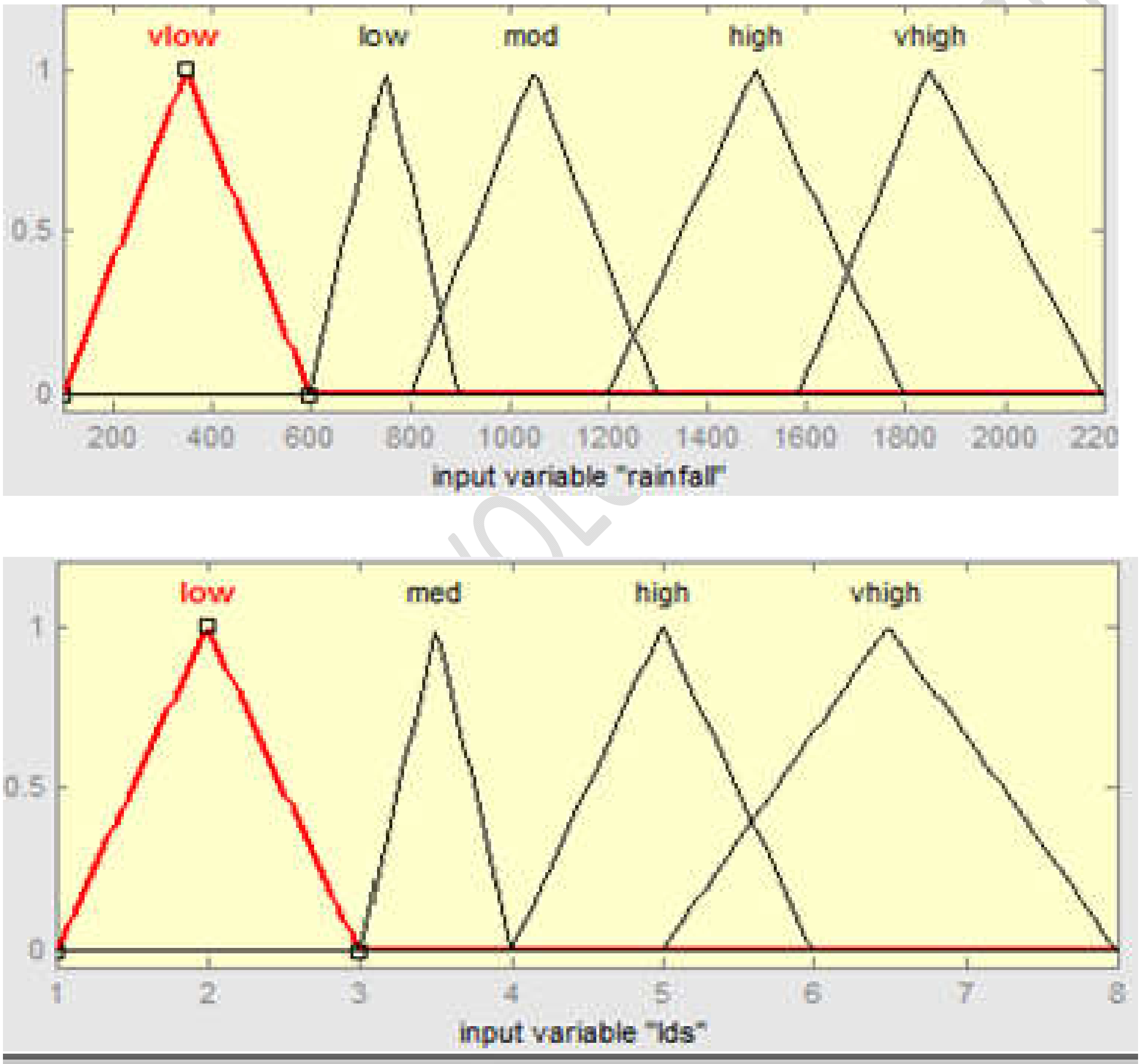


Figure 3.8: Triangular Fuzzy Membership Function of Rainfall and Length of Dry Season for Maize FIS

refers to the process of taking a crisp input value and transforming it into the degree required by the terms (Ngai, 2003). The “fuzzified” values are determined by intersecting the input value to the fuzzy membership function. In the present study triangular membership functions have been used to define the fuzzy sets for the linguistic values of the parameters. The fuzzy set membership functions represent the Rainfall are defined based on the knowledge of human expert and knowledge from (Sys, 1985; FAO, 1983; Adesemuyi, 2014).

3.4.6 Fuzzy inference generation

Fuzzy inference is guided by the fuzzy rules. The standard max–min inference algorithm was used in the fuzzy inference process, as it is a commonly used fuzzy inference strategy (Ngai, 2003). Mamdani inference is used as Equation 3.1:

$$\mu_B = \underset{i=1}{\overset{M}{Max}} \left[\underset{x \in U}{Sup} \min \left[\mu_A(x), \mu_A(x_1), \ldots \mu_A(x_n), \mu_B(y) \right] \right] \quad (3.1)$$

Whereas μA is the membership function for arbitrary set in fuzzy inference engine's input and μB is the consequence membership function for the 1^{th} rule. In the max–min composition fuzzy inference method, the min operator is used for the AND conjunction (set intersection) and the max operator is used for the OR disjunction (set union) in order to evaluate the grade of membership of the antecedent clause in each rule.

3.4.7 Defuzzification

When the inference process is complete, the resulting data for each output of the fuzzy classification system are a collection of fuzzy sets or a single, aggregate fuzzy set. The process of computing a single number that best represents the outcome of the fuzzy set evaluation is called defuzzification (Ngai, 2003). There are several existing methods that can be used for defuzzification. These include the methods of maximum or the average heights methods, and others. These methods tend to jump erratically on widely non-contiguous and non-monotonic input values (Diego, 1999). Centroid method, also referred to as the “center-of- gravity (COG)” method was chosen as it is frequently used and appears to provide a consistent and well-balanced approach. (Klir and Folger, 1998). For each output using this defuzzification method, the resultant fuzzy sets were merged into a final aggregate shape and the centroid of the aggregate shape computed.

CHAPTER FOUR

IMPLEMENTATION AND PERFORMANCE EVALUATION

4.1 Overview

This chapter discusses the implementation and performance evaluation of the decision support system for soil suitability evaluation. The implementation of the model was done using MATLAB 9.0 language, while its performance evaluation was determined both quantitatively and qualitatively. The performance metric used for the quantitative evaluation was accuracy.

4.2 Model Implementation

The model was implemented in a Matlab environment, the source code is given in Appendix A. MATLAB, a flagship software extensively used all over the world, most especially in scientific computing is well known for its numerical problem solving power. An acronym for MATrix LABoratory, MATLAB is a high- level technical computing language which integrates computation, visualization, and programming in an easy to use and interactive environment (MathWorks, 2011). The use of MATLAB is increasing day by day (McMohan, 2007; Littlefield and Hanselman, 2004), and some of the factors that supported its selection are:

i. a flexible software structure comprising of libraries, models and programs,
ii. enabled the integration of different model components in one package conveniently,
iii. fast development with MATLAB while using powerful calculation and visualization means of the package enabled the expansion of the software efficiently without developing any extra programming tools.

iv. A wide selection of TOOLBOXes, comprehensive collection of predefined functions for solving application-specific problems was already available in the MATLAB package (Nasiruzzaman, 2010).

Science and engineering students have used this software broadly for educational purposes (Chapman, 2007). Traditionally, programs written by the various users of this software package had very simple or no interfaces due to the nature and the capacity in which the MATLAB toolboxes were used. In this study, the MATLAB Fuzzy logic toolbox was used to design and create the four Fuzzy Inference Systems (one for each crop) depicted in Figures 4.1. to 4.4.

Each FIS was tested with sample data collected and the rule viewer was used to view the response from the fuzzy inference system. The rule viewer depicts the entire implication process from beginning to end, which rules are active, or how individual membership function shapes influence the results. The rule viewer was invoked using the MATLAB 'rule view' command.

The following two instructions load the fuzzy inference system 'Maize.fis' from file and use the 'rule view' to view its response.

```
maize=readfis('Maize.fis')
ruleview(maize)
```

Figure 4.5 depicts the output of these instructions. It also gives an illustration on how well the rules for the Maize FIS were able to predict the suitability of soil to the crop. Other FISs were tested in a similar manner.

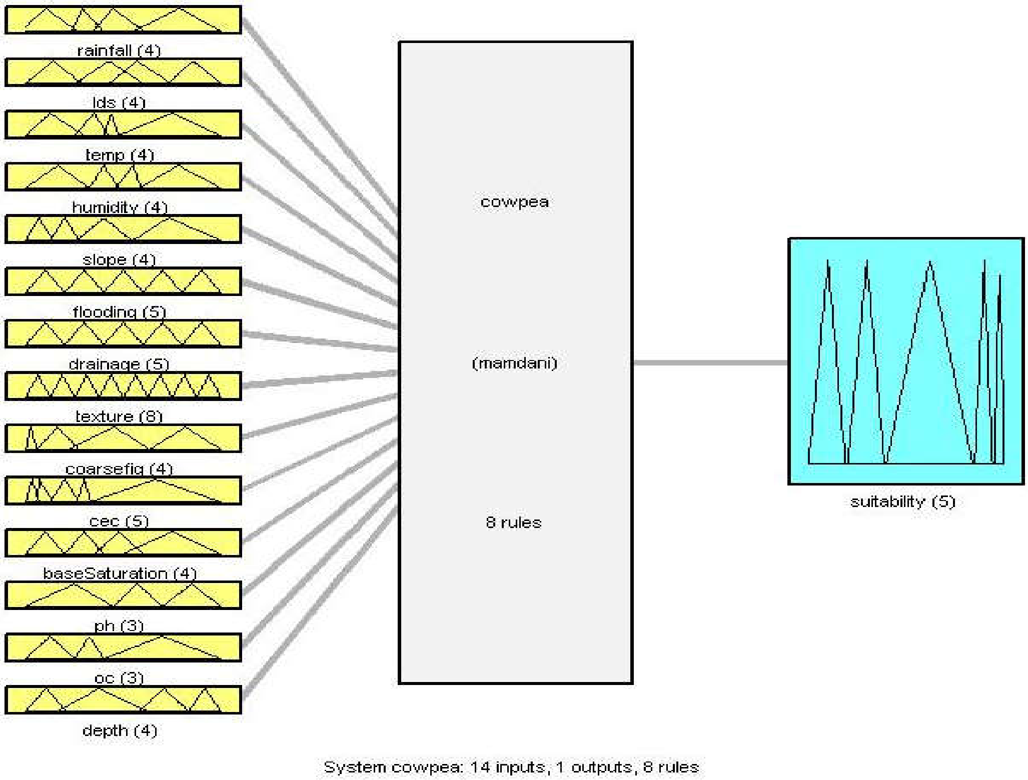


Figure 4.1: The Soil Suitability Evaluation FIS for Cowpea

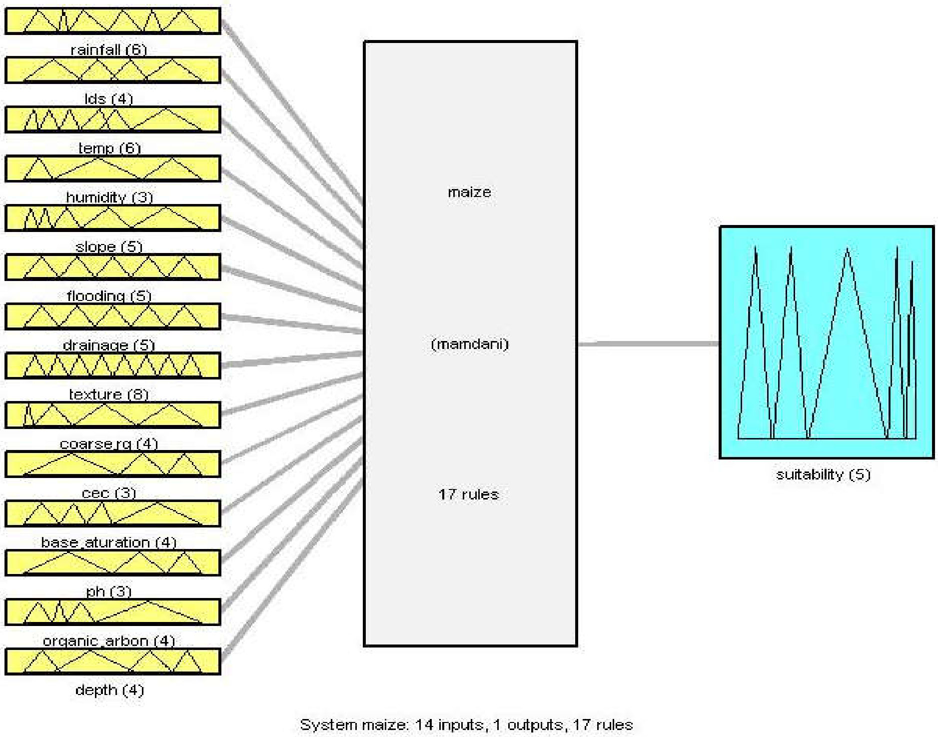


Figure 4.2: The Soil Suitability Evaluation FIS for Maize

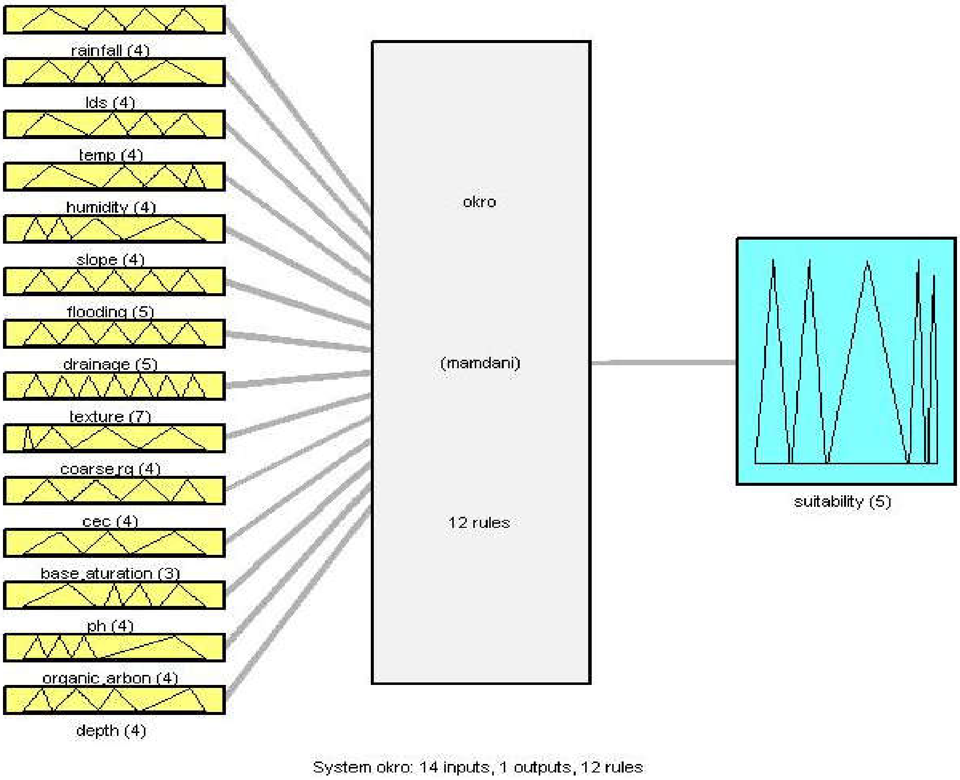


Figure 4.3: The Soil Suitability Evaluation FIS for Okro

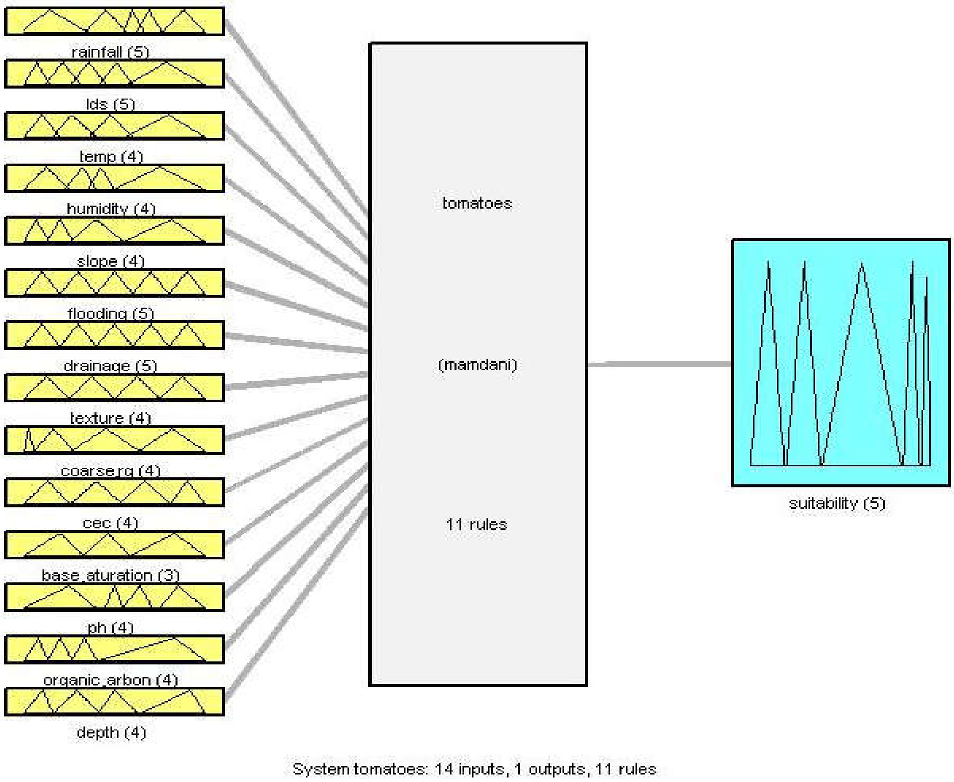


Figure 4.4: The Soil Suitability Evaluation FIS for Tomatoes

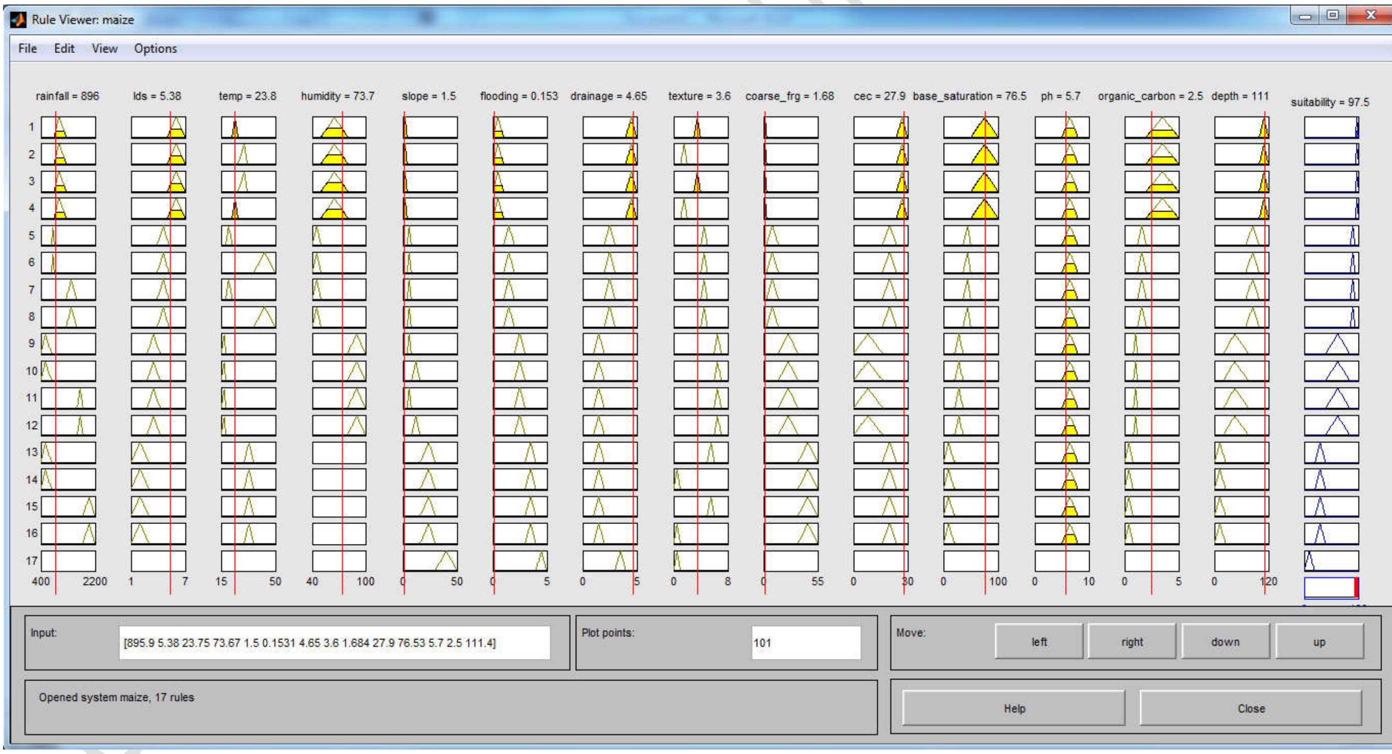


Figure 4.5: The Rule View Screen for the Maize FIS

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There have been various occasions where a more polished user interface, specifically, a Graphical User Interface (GUI) is desired together with the use of one or more toolboxes, thus, the MATLAB Inc. introduced a set of event driven components that could be used to create GUIs with the fourth version of the software. The GUI is an environment that gives the option to a programmer developing software packages for personal and problem specific uses. It allows the arrangement of information on a computer screen, in a way that is easy to understand and use. Its' use of icons, menus and a mouse rather than only text and programs written in high level language which is often not so handy for others except for programmers (Nasiruzzaman, 2010) makes it quite comfortable for use. The MATLAB GUI can be built in two ways, using the GUIDE (Graphical User Interface Development Environment), or coding from the MATLAB editor. Both options were employed in this study to build the GUI depicted in Figures 4.6 and 4.7. Both figures illustrate the ability of the system to determine the soil suitability for maize and cowpea crops, respectively. The business logic of the decision support system was developed from the MATLAB editor environment. Sample code for the system is given in Appendix. A The code fragment depicted in Figure 4.8 is executed when a user clicks the 'Evaluate' button on the GUI depicted for instance, in Figure 4.6. Figure 4.9 is an interface to automatically test the software by using randomized data. This is discussed in subsequent sections.

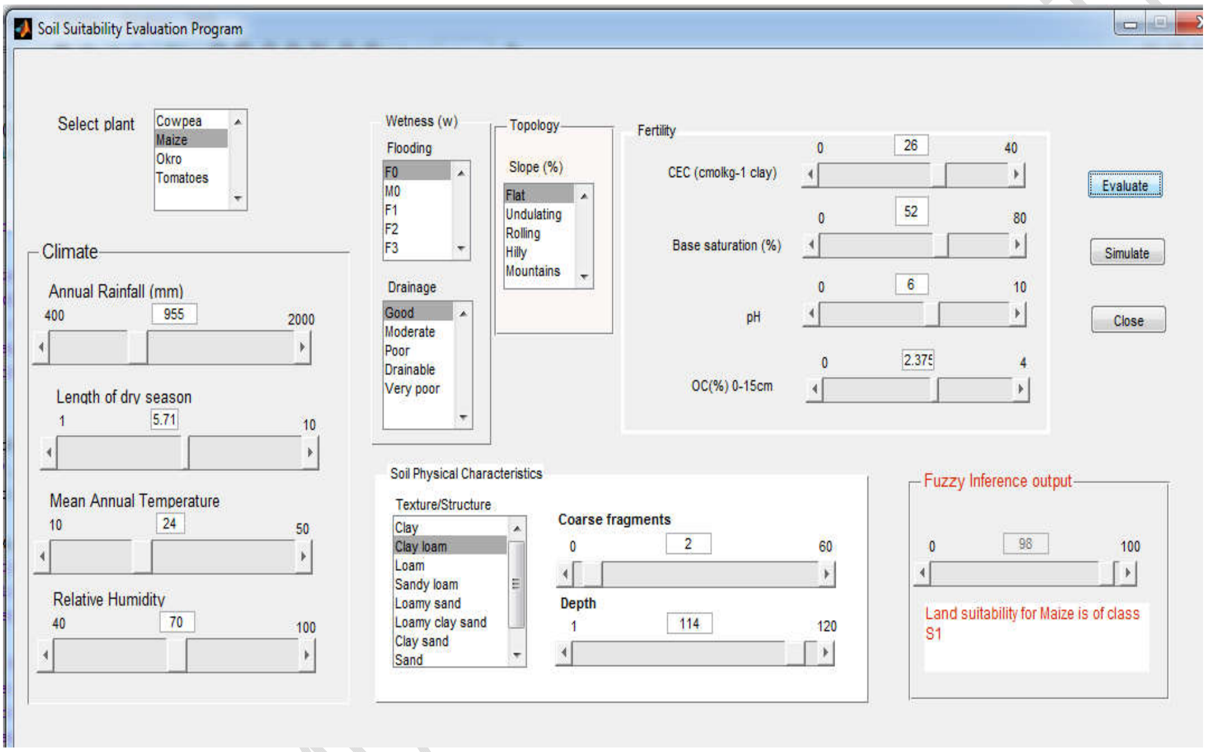


Figure 4.6: Soil Suitability Evaluation Result for Maize Crop

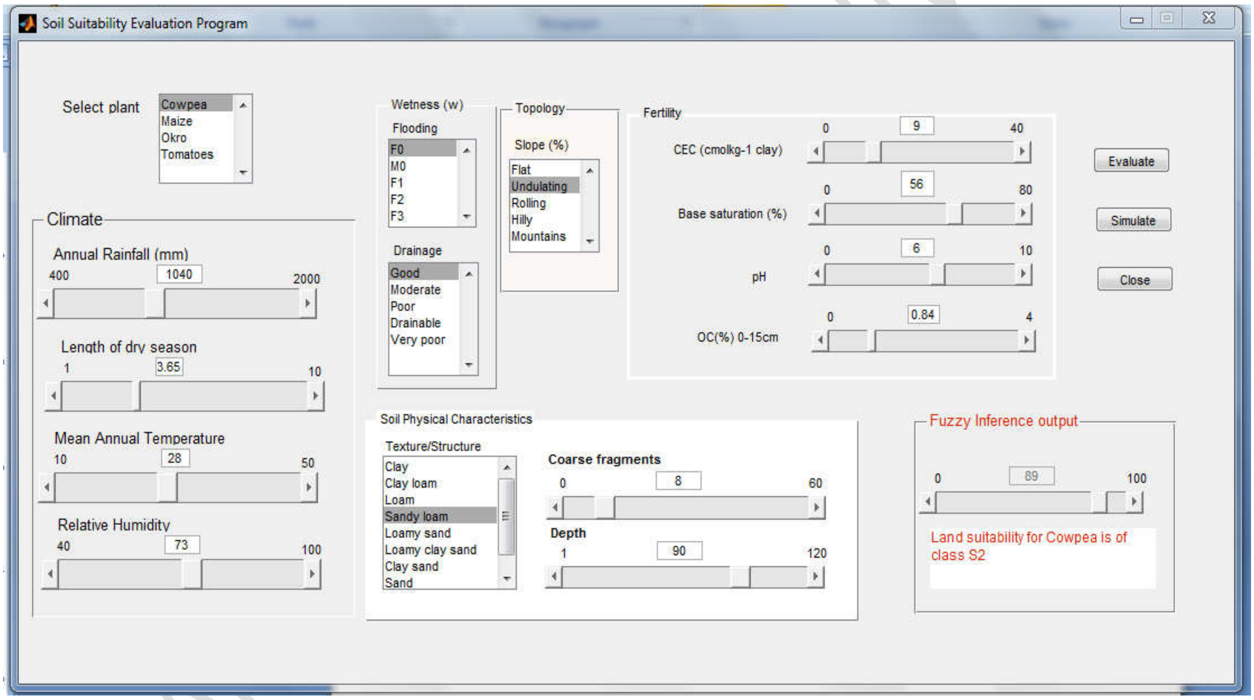


Figure 4.7: Soil Suitability Evaluation Result for Cowpea Crop

```
function output=evaluateFuzzy()
 global plant rainfall days temperature humidity slope flood drainage texture…
          fragments cec saturation ph oc depth fis
input=[rainfall, days, temperature, humidity, slope, flood, drainage, texture,…
        fragments, cec, saturation, ph, oc, depth];
  y=evalfis (input, fis);
end
```

Figure 4.8: Code Snippet to Evaluate Inference System

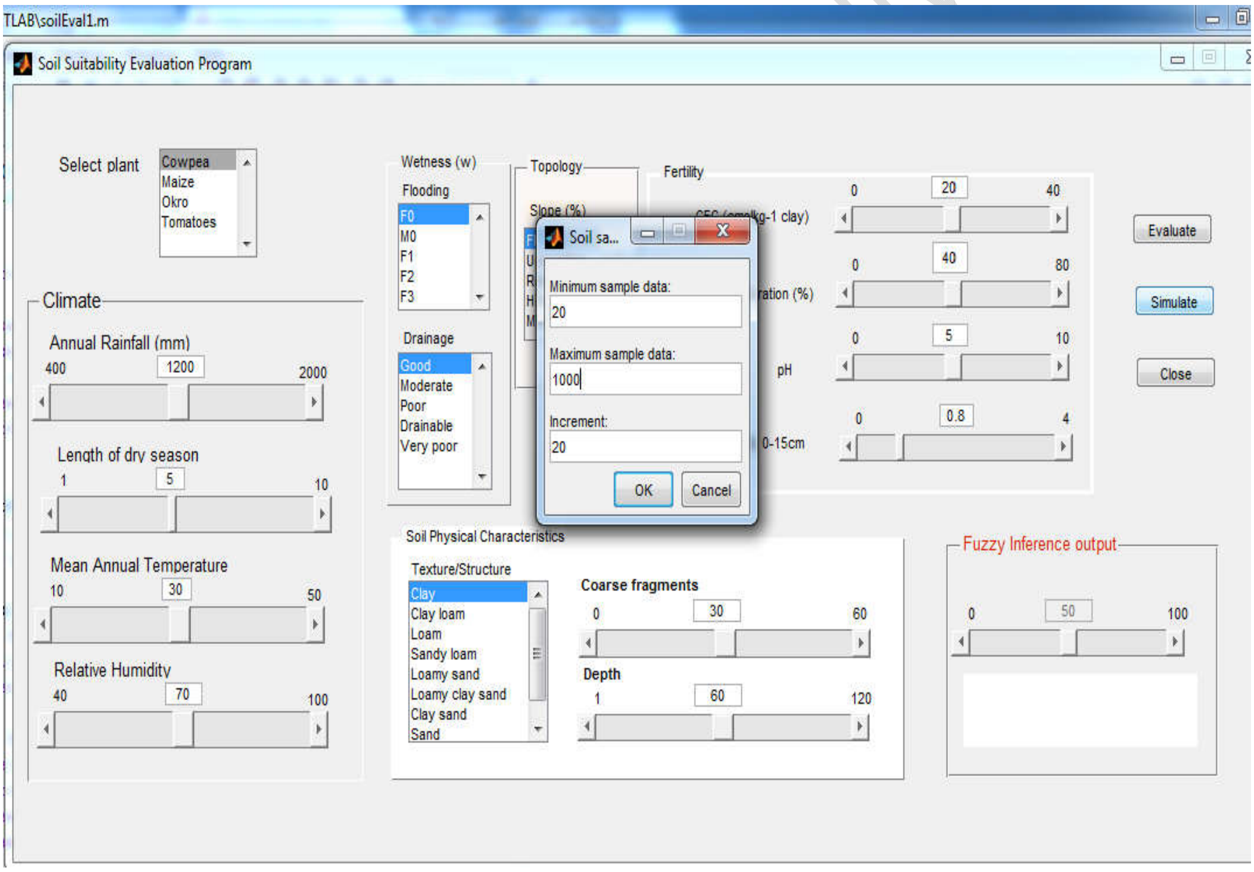


Figure 4.9: GUI for System's Simulation

4.3 Performance Evaluation

Performance evaluation is the process of quantifying the services delivered by a system. The system was evaluated both quantitatively and qualitatively. To quantitatively evaluate its performance, performance metric accuracy was used. Accuracy, being the condition or the quality of being true, correct or exact was chosen as a performance metric in order to determine the degree of correctness of the system's response in terms of the precision of decisions made in-line with the fuzzy inference system when determining the soil suitability for plants. The equation used to determine the system's accuracy was

$$accuracy = \frac{correct\ decisions}{total\ decisions} * 100 \qquad (4.1)$$

Soil physical properties and environment variables used for modeling were randomly generated from the uniform distribution. The uniform cumulative distribution function is

$$p = F(x|a,b) = \frac{x-a}{b-a} I_{[a,b]}(x) \qquad (4.2)$$

The uniform distribution (also called rectangular) has a constant probability density function (pdf) between its two parameters a (the minimum) and b (the maximum). The standard uniform distribution (a = 0 and b = 1) is a special case of the beta distribution, obtained by setting both of its parameters to 1.

The MATLAB function '*unifrnd*' can be used to return array of random numbers generated from the continuous uniform distributions. For instance, R = unifrnd(A,B,m,n) returns an array $R_{(m*n)}$ of random numbers generated from the continuous uniform distributions with lower and upper endpoints specified by A and B, respectively.

In an experiment to determine how well the system can accurately predict suitability of soil, data for soil samples were randomly generated from uniform distribution as discussed above. The data generated represented the soil's physical characteristics and climatic requirements. Table 4.1 depicts the efficiency (in terms of accuracy) of the system in determining soil suitability for the four crops used in this study. The system's overall accuracy was 92.7%. The inference system to determine soil suitability for cowpea was 98.8% accurate, inference system for maize was 96.8% accurate, inference system for okro was 88.2% accurate and the inference system for tomatoes was 86.8% accurate. Figures 4.10 and 4.11 depict the outputs of the system used to accurately determine soil suitability of different soil samples. Figure 4.12 depicts an output of the fuzzy inference engine for the cowpea crop. The inference subsystem was able to correctly identify the soil suitability classes present in one thousand data sample. In the sample, all the 580 for class S1 were correctly identified, ditto for the 110 samples of class S2 and 140 samples for class S3, respectively. From the 140 samples of class N1, only 120 samples were correctly identified, while 15 of the samples of class N2 were correctly identified.

Analysis and evaluation of the outputs generated by the system was also carried out using the qualitative evaluation method. The Mean Opinion Score (MOS) was used for the qualitative evaluation of the system. The MOS evaluation was carried out to determine the ability of the software to accurately evaluate soil requirements for crops. Chosen experts (seven) in Agriculture discipline, who have knowledge of soil and climatic requirements of crops were asked to determine the suitability of some sample data. This is represented as experiment (see Figure 4.13). On the other hand the system was also used to determine the suitability of these same samples. Afterwards, the experts' responses were compared to the output of the software and the experts were asked to rate (on a Liker's scale of 1-5) the system in terms of

Table 4.1: System's Accuracy

Iteration	Cowpea	Maize	Okro	Tomatoes	Accuracy
20	100	100	93	92	
40	100	98	92	90	
60	100	96	90	89	
80	96	96	84	82	
100	98	94	82	81	
Accuracy	98.8	96.8	88.2	86.8	**92.7**

its output. That is, is the system's output in agreement to theirs or not? Table 4.2. gives the experts' ratings of the system's output for all the data sample (experiment).

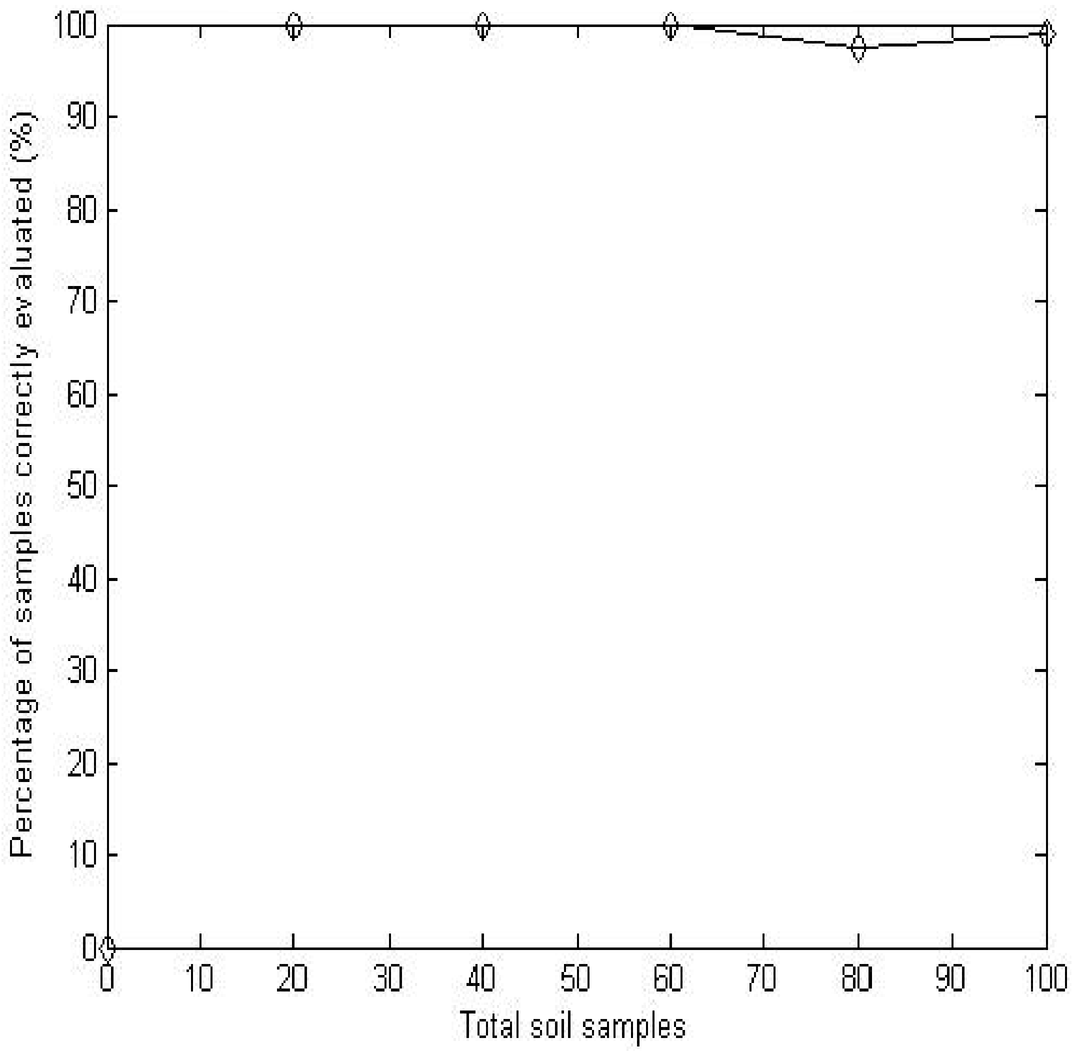

Percentage of samples correctly evaluated (%)
Total soil samples
0
10
20
30
40
50
60
70
80
90
100

Figure 4.10: Performance of Soil Suitability Evaluation of 100 Soil Samples

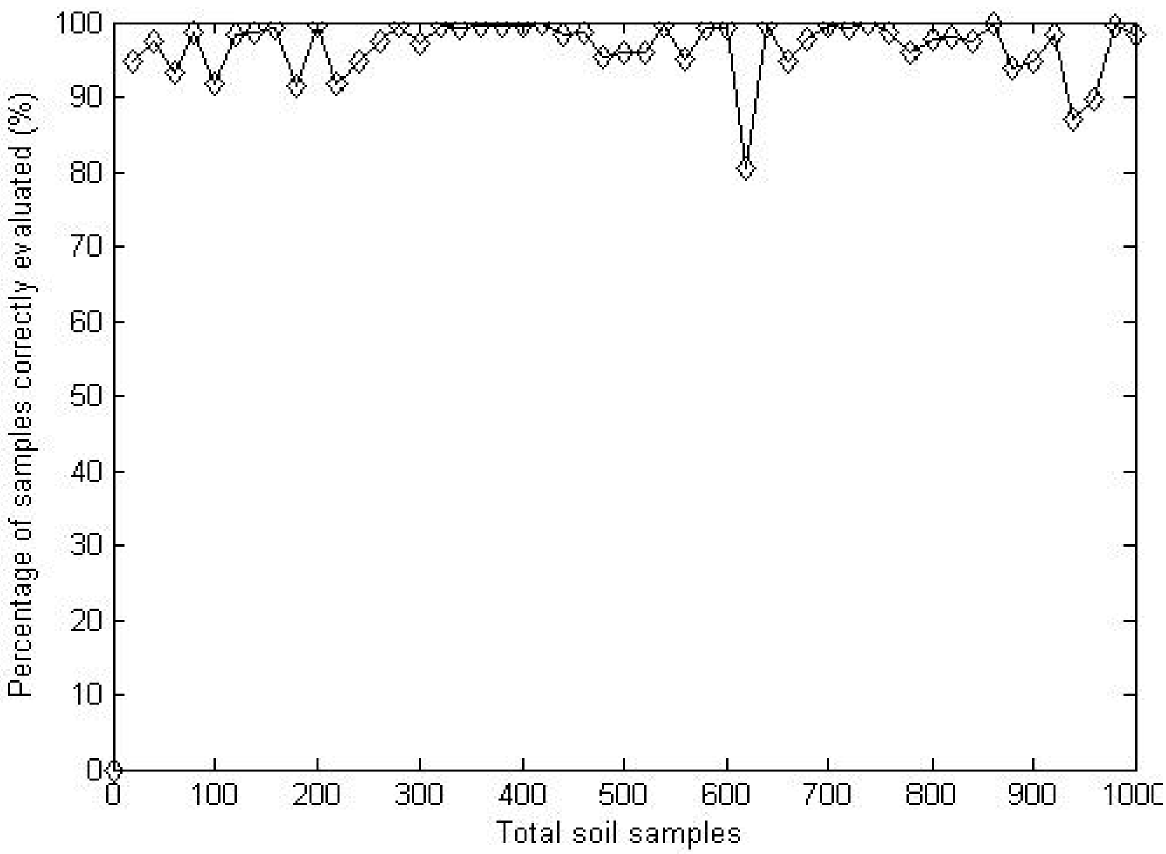


Figure 4.11: Performance of Soil Suitability Evaluation of 1000 Soil Samples

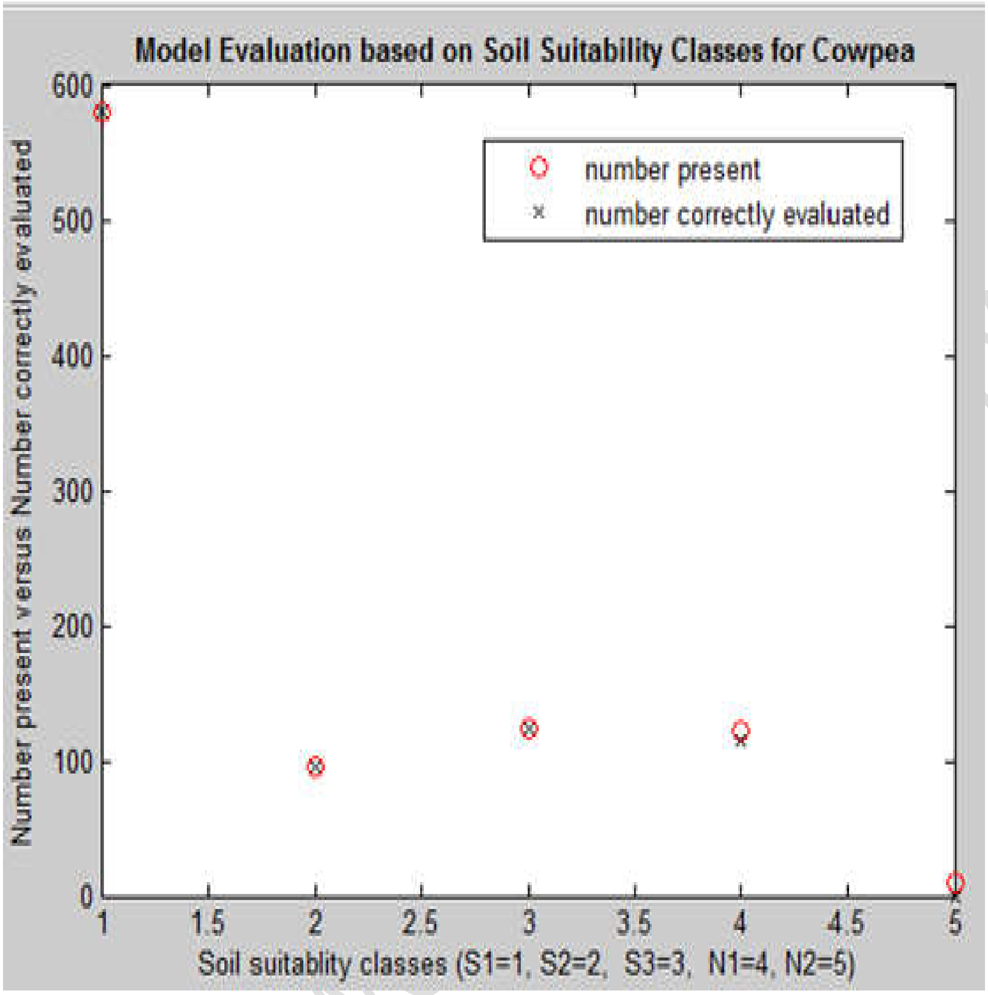


Figure 4.12: Soil Suitability Classes Present in 1000 Soil Samples of Cowpea

Land Quality	Maize	Maize	Cowpea	Cowpea	Okro	Maize	Maize	Okro	Tomatoes	Cowpea	Cowpea	Tomatoes	Tomatoes	Okro
Annual rainfall	900	800	1230	900	1400	605	1100	965	1000	700	400	1320	1550	1800
Length of dry season	6	4.5	5	4	3.5	3	5	4.5	4.5	5	8	3.5	2.5	2.5
Mean Ann. Temp	24	23	32	28	34	17	30	28	24	24	18	17	11	24
Humidity	67	45	85	70	75	90	70	65	67	65	55	74	78	82
Slope	1	3	2	6	2	7	3	6	3	12	-	6	14	10
Flooding	F0	M0	F0	F0	F0	F1	F0	F1	F0	F1	F3	F1	F2	F2
Drainage	GOOD	MODE	GOOD	GOOD	GOOD	POOR	GOOD	MODE	GOOD	GOOD	V. POOR	MODE	DRAINABL	AINABLE
Texture	CL	LS	LS	SL	SL	LCS	L	SL	CL	SCL	CL	SL	S	C
Corse fragments	2	8	2	8	2	28	1	5	2	28	40	12	19	33
Depth	110	90	110	80	85	60	127	58	87	45	18	48	34	43
CEC	25	19	12	9	22	14	27	7	27	6	1.8	23	11	5
base satration	55	43	68	50	67	25	60	89	39	30	0	33	15	87
ph	6.5	6.5	6.2	6.8	5.8	6.5	5.7	6.9	5.8	5.7	7.6	6.8	4.8	6
OC	3	1.7	0.9	0.96	2	0.9	4	1.1	1.9	0.55	0.4	1	0.6	0.2
Suitability														

Figure 4.13: Soil Physical and Climatic Requirements for Crops

Table 4.2: Experts' Rating of System's Output

Experts	**Experiments/Ratings**														**Average rating**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
1	5	5	5	5	4	5	5	4	3	5	5	4	4	4	4.50
2	5	5	5	5	3	5	4	3	4	5	5	3	4	4	4.29
3	5	5	5	5	3	5	5	4	4	5	5	4	4	3	4.43
4	5	5	5	5	4	5	5	4	3	5	5	3	3	4	4.36
5	5	5	5	5	3	5	4	4	4	5	5	4	4	4	4.43
6	5	5	5	5	5	5	5	4	3	5	5	3	4	3	4.43
7	5	5	5	5	3	4	5	3	4	5	5	4	4	4	4.36
															4.40/5.00

Key:

1. Strongly disagree
2. Disagree
3. No opinion
4. Agree
5. Strongly agree

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

Making the correct decision at the right time has been a major problem in soil suitability evaluation, because decision- makers need to analyze and absorb a large quantity of information in a short time. The information can be vague and sometime conflicting in nature. Fuzzy logic provides a different way to approach a classification problem. This system focuses on what the system should do rather than only trying to model how it works. It concentrates on solving problem rather than modeling the problem mathematically. On the other hand, the fuzzy approach requires a sufficient expert knowledge for the formulation of the rule base, the combination of the sets and the defuzzification. This research presented a fuzzy based decision support system to assist decision maker. All parameters of the problem that was required to build the system have been defined and modeled using fuzzy sets. The rules for the fuzzy inference system were extracted from researches and experts opinion. Fourteen critical factors which are above all considerable for decision making and the typical land suitability decisions are rainfall, length of dry season, temperature, humidity, slope, flooding, drainage, texture, coarse fragment, depth, CEC, base saturation, pH, and OC. The suitability problem is structured to fit into the framework of decision-making. The criteria are organized in the hierarchy (figure 3.5) to facilitate incorporation of expert knowledge from various disciplines. Keeping in mind the complexity of decision-making the criteria are grouped at several stages over the hierarchy. Triangular membership function was used for the input and output membership function. This is as a result of its simplicity. The fuzzy inference engine used is the Mandani and the system was implemented with fuzzy logic toolbox in Matlab. Four different FIS was used, one for each crop.

This is done for the simplicity of the system. The land evaluation used in the study area is qualitative and no economic evaluation was conducted.

The land suitability model can be improved if further data are provided. Soil data and more meteorological data will improve the accuracy and purity of the output. Performance evaluation is done using expert validation and prototype testing. The results of the prototype evaluation are satisfactory and support the view that the system has performed its functions as expected. The result of the subjective evaluation using mean opinion score is described in Table 4.2. The performance evaluation is describe in Table 4.1 with the accuracy of 92.7%.

5.2 Conclusion

The developed system has been evaluated by the experts the result shows that it is capable of determining the land suitability class given the characteristics of the land, therefore, which can be used to determine the appropriate crops to be cultivated.

Fuzzy inference method can represent and manipulate agriculture knowledge that is incomplete or vague and can be used to determine land limitation rating. The rating value is used to determine limitation level of the land. At the similar limitation level for different types of crops, the rating value is used to determine what the most suitable crops to cultivate for the existing condition of the land. The greater the rating value the more suitable crop for land of interest.

5.3 Recommendation for Future Work

Present study is concentrated on four crops and fourteen land characteristics. Image processing may be included to process images representing soil type automatically.

APPENDIX A

SOURCE CODE LISTING

```
function varargout = soilEval1(varargin)
% SOILEVAL1 MATLAB code for soilEval1.fig
%      SOILEVAL1, by itself, creates a new SOILEVAL1 or raises the
existing
%      singleton*.
%
%      H = SOILEVAL1 returns the handle to a new SOILEVAL1 or the
handle to
%      the existing singleton*.
%
%      SOILEVAL1('CALLBACK',hObject,eventData,handles,...) calls
the local
%      function named CALLBACK in SOILEVAL1.M with the given input
arguments.
%
%      SOILEVAL1('Property','Value',...) creates a new SOILEVAL1 or
raises the
%      existing singleton*.  Starting from the left, property value
pairs are
%      applied to the GUI before soilEval1_OpeningFcn gets called.
An
%      unrecognized property name or invalid value makes property
application
%      stop.  All inputs are passed to soilEval1_OpeningFcn via
varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows
only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help soilEval1

% Last Modified by GUIDE v2.5 10-Jan-2015 01:15:01

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @soilEval1_OpeningFcn, ...
                   'gui_OutputFcn',  @soilEval1_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
```

APPENDIX B

Land use requirement for Maize.

Land qualities	**Suitability classes**				
	S1 (100-95)	S2 (94-85)	S3 (84-40)	N1 (39-20)	N2 (19-0)
Climate (c)					
Annual rainfall (mm)	850-1250	850-750	750-600	600-500	-
		1250-1600	1600-1800	>1800	-
Length of dry season (months)	5-7	4-5	3-4	2-3	-
Mean annual maximum temp. (°C)	22-26	22-18	18-16	36-30	-
	26-32	>36			
Relative humidity (%)	50-80	50-42	>80	-	-
Topography (t)					
Slope (%)	0-2	2-4	4-8	18-16	
	0-4	4-8	8-16	16-30	>30
Wetness (w)					
Flooding	F0	M0	F1	F2	F3
Drainage	Good	Moderate	Poor	Poor	Drainable
Soil physical properties (s)					
Texture/Structure	CL, L	SL, LS	LCS	CS, S	S
Coarse fragments(%) 0-10 cm	<3	3-15	15-35	35-55	-
Depth (cm)	>100	70-100	25-70	25	-
Fertility (f)					
CEC (cmolkg-1 clay)	>24	16-24	<16(-)	16(+)	-
Base saturation (%)	>50	35-50	20-35	<20	-
pH	5.5-7.0	5.5-7.0	5.0-8.0	5.0-8.0	
OC(%) 0-15cm	>2	1.2-2	0.8-1.2	<0.8	-

modified from Adesemuyi. 2014

APPENDIX C

Land use requirement for Cowpea.

Land qualities	**Suitability classes**			
	S1 (100-95)	S2 (94-85)	S3 (84-40)	N1 (39-20)
Climate (c)				
Annual rainfall (mm)	>1200	800-1200	600-800	-
Length of dry season (months)	>3	3-5	4-6	-
Mean annual maximum temp. (°C)	>29	27-29	22-27	-
Relative humidity (%)	>80	68-75	60-68	-
Topography (t)				
Slope (%)	0-4	4-8	8-16	>16
Wetness (w)				
Flooding	F0	F0	F1	-
Drainage	good	good	good	Poor
Soil physical properties (s)				
Texture	LS	SL	SCL	Any
Structure	Crumb	Crumb	S.a blocky	Columnar
Coarse fragments (vol. %) 0-10 cm	<3	3-12	12-35	-
Depth (cm)	>100	70-100	25-70	-
Fertility (f)				
Cation exchange capacity (cmol/kg)	>10	8-10	4-8	2-4
Base saturation	>60	40-60	20-40	-
pH	6.0-6.5	6.0-7.0	5.5-6.0	4.5-5.0
Organic carbon (%) 0-15 cm	>0.8-1.0	0.8-1.0	0.5-0.6	< 0.5

modified from Ogunwale *et al*. 2009

APPENDIX D

Land use requirement for Tomatoe.

Land qualities	**Suitability classes**			
	S1 (100-95)	S2 (94-85)	S3 (84-40)	N1 (39-20)
1 Climate (c):				
Annual rainfall (mm)	850-1250	1250-1450	1450-1700	-
Length of dry season (months)	4-5	3-4	2-3	
Mean annual max temp.(0C)	20-27	15-20	10-15	-
Relative humidity (%)	60-70	70-75	75-80	-
2 Topography (t):				
Slope (%)	0-4	4-8	8-16	-
3 Wetness (w)				
Flooding	F0	F1	F2	-
Drainage	good	moderate	Drainable	-
4 Soil physical Characteristics (s):				
Texture/Structure	CL,SL	SL,LS	LCS,S,C	-
Coarse fragments(%) 0-10 cm	<3	3-15	15-35	-
Depth cm	>75	50-75	20-50	-
5 Fertility (f):				
CEC (cmolkg-1 clay)	>24	16-24	8-16	-
Base saturation (%)	>35	20-35	<20	-
pH	5.5-6.5	6.5-7.0	4.5-5.5	-
OC(%) 0-15cm	>1.2	0.8-1.2	0.4-0.8	-

modified from Ayodele and Aruloba. 2007.

APPENDIX E

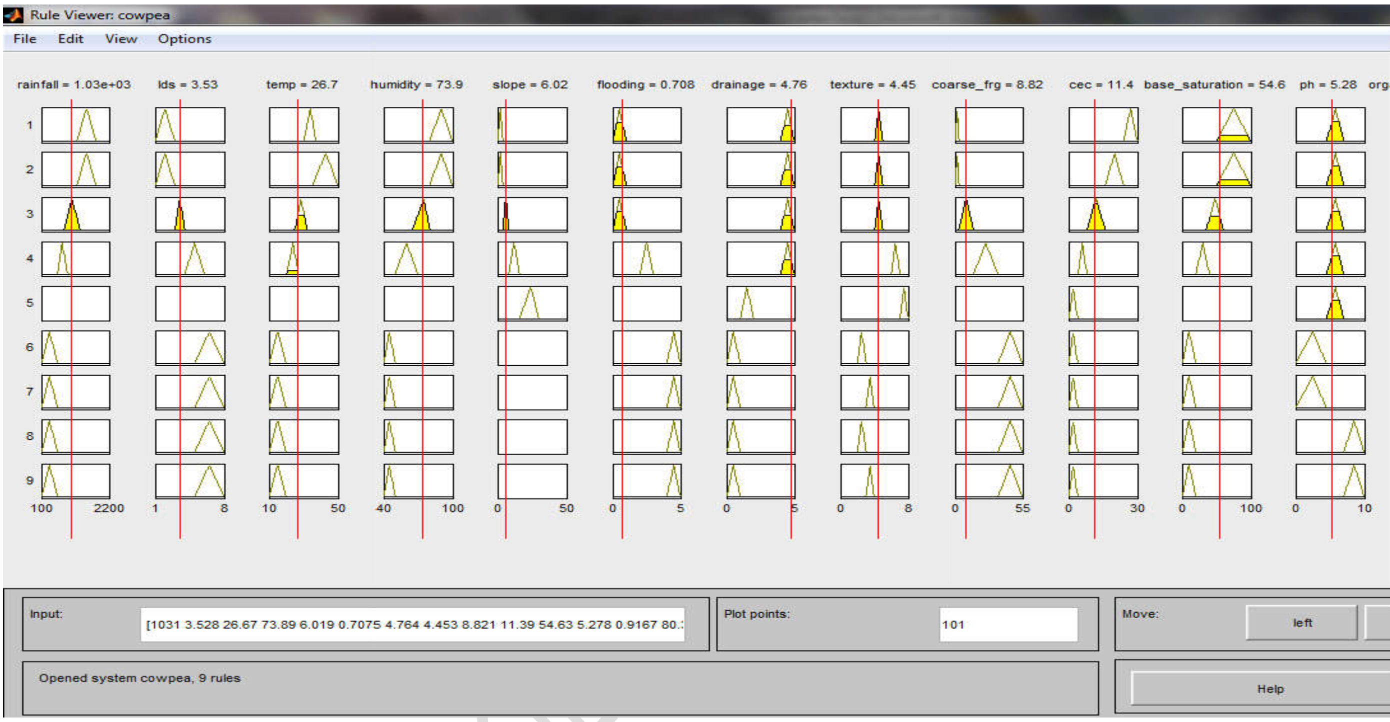
Land use requirement for Okro.

Land qualities	**Suitability classes**			
	S1 (100-95)	S2 (94-85)	S3 (84-40)	N1 (39-20)
1 Climate (c):				
Annual rainfall (mm)	1250-1750	1250-850	>1700-2000+	-
Length of dry season (days)	3-4	4-5	2-3	-
Mean annual max temp.(0C)	30-35	25-30	20-25	-
Relative humidity (%)	70-80	60-70	80-85	
2 Topography (t):				
Slope (%)	0-4	4-8	8-16	-
3 Wetness (w)				
Flooding	F0	F1	F2	-
Drainage	Drained	moderate	Drainable	-
4 Soil physical Characteristics (s):				
Texture/Structure	CL,SL	SL,LS	LCS,S,C	-
Coarse fragments(%) 0-10 cm	<3	3-15	15-35	-
Depth	>75	50-75	20-50	-
5 Fertility (f):				
CEC (cmolkg-1 clay)	>24	6-24	8-16	-
Base saturation (%)	>35	20-35	<20	-
pH	5.5-6.5	6.5-7.0	4.5-5.5	-
OC(%) 0-15cm	>1.2	0.8-1.2	0.4-0.8	-

modified from Ayodele and Aruloba. 2007.

APPENDIX F

RULE VIEW OF THE FOUR CROPS



The Rule View Screen for the Cowpea FIS