CHAPTER FIVE: PROPOSED STRATEGY AND STRUCTURE OF LAND SUITABILITY EVALUATION FOR ERITREA

5.1 Introduction

Individual land users operating within a large set of environmental and legal systems always make different choices of land use. So it is no surprising, therefore, that differences should exist within the structures of land uses in different countries, even within more developed countries. The climate and other aspects of the physical environment, population density and land area are totally different and these factors have a very significant effect on the structure and composition of land uses (Mather, 1986). To improve existing land use or to establish a new one, effective evaluation of land is necessary.

As it has been stated in the previous chapter, different land capability and suitability classifications are used in different parts of the world. These classification types, though they are different, all have the objective to evaluate the land and classify it to the most suitable use it can offer without degrading the environment. The adoption of such evaluation strategy as it is or after modifying it to fit into their respective situations has been practised in both developed and developing countries. The FAO Framework for Land Evaluation (1976) proves to be more flexible and easy to manipulate for developing countries like Eritrea than the land capability system of the USDA, which is a broad and rigid classification system (Smyth, 1977). In this chapter, the present land evaluation system of Eritrea will be analysed and a more suitable land evaluation strategy and structure will be proposed.

5.2 Present land evaluation in Eritrea

As it has been mentioned earlier, Eritrea was officially declared an independent country on May 24th, 1993. Since then the government has tried to consolidate different related ministries into one major ministry dealing with land. Land was initially under the Ministry of Agriculture, but because of its importance and sensitive nature, it became the responsibility of the Commission on 1994. In 1997 it became the responsibility of the Ministry of Land, Water and Environment. The ministry has three departments and land use and cartography is a branch under the Department of

Land and its major activities include allocating of land for commercial agriculture. In the process land is evaluated using the USDA system (Klingebiel and Montgomery, 1961) at a broad or small-scale level to judge its potential and categorize it according to its capability. To help its activity the ministry printed a very broad agro-ecological zone map of Eritrea at a scale of 1:1,200,000 in 1997. The map is presented on page 18 of chapter one.

As far as land use experts are concerned, the branch has only 13 experts who are mostly new graduates from university and one senior person with a doctor's degree who has a very good background in land use planning, as their facilitator. This indicates the shortage of experts in the field. Human resource development is a main objective of the government and the ministry however. Because of this three students are presently conducting postgraduate studies in land use planning in South Africa and the program will continue to minimize the existing shortages. There is no strategy of land evaluation except the USDA system (Araya, personal communication) and it is believed that the following proposal for a land evaluation system could be used as a guideline for evaluation at different levels of intensity. The USDA system can also be used at a reconnaissance level to identify the potential arable land at national level.

5.3 Proposed strategy of land evaluation for Eritrea

Land suitability evaluation scored marked achievements over the past two to three decades in defining the most suitable area of land for a specific use. During the process of suitability evaluation, sustainability should be maintained and input/output ratio should be satisfactory for the land user. Eritrea as new nation should learn more from the past experience of this discipline. Even though the process is long and demanding (capital and experts), effort should be put for achieving a sustainable land use. Eritrea is a country in which the climate is suitable for several field crops, fruits and vegetables, but the erratic nature of the rain does not allow for practicing a sustainable rainfed agricultural production. This calls for effective and careful planning in terms of using the scarcest resource i.e. moisture availability. For the purpose of this paper, two cereal crops, i.e. wheat and sorghum, have been chosen as examples. The main reason for choosing these two crops are firstly they are highly consumed by the majority of Eritrean people and secondly they represent crops adapted to the highland and lowland climate of Eritrea respectively. In the future this process can be repeated for other crops. The climatic and soil requirements of other crops grown in Eritrea are presented in appendix 3.

Land could be evaluated for general purpose, where the land utilization type is not known or for a specific purpose, where the land utilization type is specified in a very detailed manner. In the latter case, evaluation is done to find areas of land which satisfy the requirements of the land utilization type with reasonable economic return and little social and environmental disturbances. For such evaluation, land suitability classification can give the required information, while for the former kind of land evaluation the USDA system (land capability) could be adequate. Such system, though effective, is only a subjective way of classifying land, i.e. it doesn't include economic comparisons between alternative uses. On the other hand, it gives the limitations of certain land for specific land uses, and this helps to indicate the actions needed to control erosion and other forms of soil degradation and thus improve the condition of the land.

Land amelioration in terms of fertilizing, irrigating, desalinization etc. could improve the quality of land and shift the land class e.g. from Class IIIe to Class IIe, but the cost of amortization should be borne in mind. If the government or NGOs subsidize the cost, the benefit-cost ratio could be greater than one which is feasible but if individual farmers are expected to pay for such kind of land improvement, the benefit-cost ratio will be less than one which makes the land not suitable (Moormann, 1981).

FAO (1976) and Dent and Young (1981) described step-by-step procedure of land evaluation for specific purposes (Figure 5.1). If economic and other factors allow, this procedure can be adopted after few modifications to the Eritrean situation. The procedures that need to be followed are:

I. Initial consultation (objectives, data and assumption and planning of the evaluation).
II. Description of the relevant kinds of land uses (major kind or LUT's).
III. Ascertaining the requirements of each land use type.

IV. Description of land mapping units through soil/land resource survey.

V. Rating the land qualities relevant for the land use type concerned.

VI. Comparison (matching) of land use requirement with land quality.

VII. Land suitability classification (qualitative and quantitative).

VIII. Presentation of the land evaluation results.

It should be emphasized here that land suitability evaluation is an interdisciplinary activity involving many scientific disciplines from natural and social sciences and should, therefore, be carried out by a team of specialists representing both scientific camps (Breimer, Van Kekem and Van Reuler, 1986). The structure of the suitability evaluation process is shown in Figure 5.1.

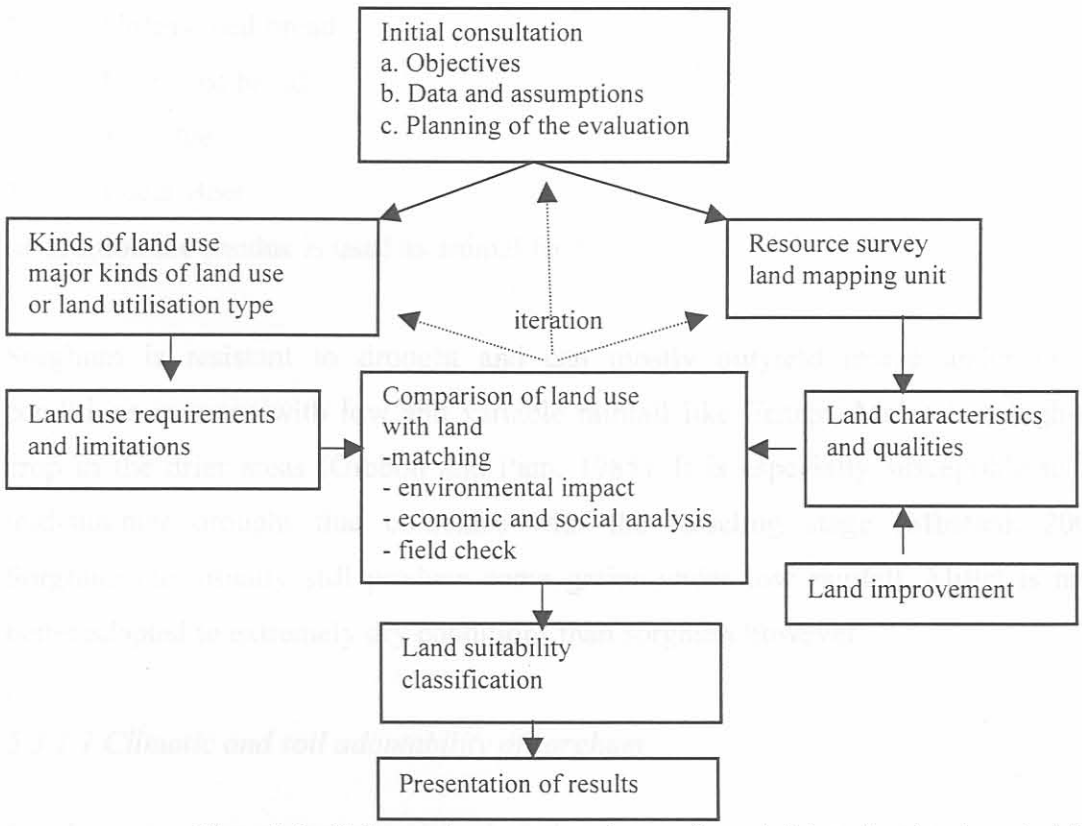

Fig. 5.1 Schematic presentation of activities in land suitability evaluation (From Dent and Young, 1981)

Taking the objective of the Eritrean government as to be self sufficient in food, the next procedure would be to find a strategy to achieve this objective. One way of doing this is through producing enough carbohydrate and protein that fulfills the demand of the people. Sorghum and wheat are among the major cereal crops, which have high carbohydrate content. The requirements of these two crops should be specified so that efforts could be directed to satisfy those needs. These needs of the crops can only be fulfilled from the land so efforts should be directed for investigating the quality and limitations of the land. The following section deals with the establishing of the requirements and identifying the most limiting land qualities for its successful production.

5.3.1 Requirements for Sorghum production (Sorghum bicolor)

Sorghum is the fourth important tropical cereal crop after wheat, rice and maize. It is one of the staple foods in Eritrea. It is used for human consumption in the following four main ways and is one of the most highly consumed crops:

1. Unleavened bread
2. Leavened bread
3. Porridge
4. Local Beer

In addition the residue is used as animal feed

Sorghum is resistant to drought and can mostly outyield maize under rainfed conditions in areas with low and variable rainfall like Eritrea. Maize is a high-risk crop in the drier areas (Gibbon and Pain, 1985). It is especially susceptible to any mid-summer drought that coincides with the tasseling stage (Mbatani, 2000). Sorghum can usually still produce some grains under low rainfall. Millet is much better adapted to extremely dry conditions than sorghum however

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5.3.1.1 Climatic and soil adaptability of sorghum

Sorghum is a warm season plant but there are some varieties that can grow in temperate regions. With the advancement of breeding of early maturing varieties, sorghum can grow on average annual rainfall of up to 380 mm (Rios and Weibel, 1984). In general sorghum can tolerate drought than maize. Gibbon and Pain (1985) gave five possible reasons for this, these are:

I. Sorghum has very deep and extensive root system and becomes well established before the stem and leaf growth accelerates.

II. The roots contain silica, which maintain their form during drought period.

III. The leaf area is limited and can be reduced further by inward rolling during drought.

IV. Sorghum usually has a much greater water use efficiency than maize.

The plant can suspend growth during periods of drought and resume growth when conditions become favourable.

Boedt and Laker (1985) showed that maize could actually extract nearly 20% more water than sorghum from the soil before it shows the first sign of stress. They found that sorghum extract much more slowly than maize, however. This gives two advantages of sorghum over maize:

(i) The total water requirement of sorghum over the whole growing season is less than for maize.

(ii) Sorghum will not run out of water so easily between successive rainfall events and can thus survive the effects of prolonged periods between rains than maize.

The minimum temperature for germination of the seed ranges from 7-10 but the minimum temperature for subsequent plant growth is about $16^{\circ}C$. Maximum temperature more than $38^{\circ}C$ are detrimental, particularly during the panicle development stage (Rios and Weibel, 1984).

Sorghum has different reactions to photoperiod and temperature changes but, as Gibbon and Pain (1985) suggested, the timing of flowering is influenced by the interaction of genotype, photoperiod and temperature. According to them, based on the work done in Northern Nigeria, some successive shorter days may induce flowering.

Sorghum can grow well in a wide range of soils but it prefers Vertisols and Alfisols with good drainage (Norman, Pearson and Searle, 1984). Vertisols have high water holding capacity, which makes them good for sorghum production by allowing the plant to use the stored water through its deep and extensive root system. Vertisols hold their water very tightly and release it slowly. This slow release is compatible with sorghum, which extracts water slowly. Based on experience many farmers all over the world, from the commercial farmers in the "Blacklands" of Texas to small-scale tribal farmers of South Africa, Know that they can grow sorghum on these black clay soil, but not maize. In the drier areas, like the central plateau of Burkina Faso, small-scale farmers grow sorghum on the clayey soils and millet on the sandy soils (Laker, personal communication). In Eritrea farmers prefer clay soils on account of their water holding capacity and sandy loam soils for their workability. The experience of other countries should be used as a learning process and could be applied in Eritrea for land evaluation and land use planning through technology transfer. The ideal texture for sorghum production is medium to heavy clay soils but it can survive on sandy soils as well. The favourable pH for the plant ranges from 5.5 to 8.4 (Landon, 1991).

5.3.1.2 Cultural practice for sorghum production

Sorghum prefers well-prepared seedbed free from weeds, when the soil is sufficiently moist to initiate rapid germination. One of the main parameters in the CYSLAMB crop model for maize is the determination of planting opportunity, when there is adequate moisture available in the soil for planting (Mtabani, 2000). A similar parameter should be developed for sorghum in Eritrea. The amount of seed to be sown per hectare depends on variability of seed, soil moisture availability and nutrient status of the soil. These factors also determine the number of plants per hectare (Rios and Weibel, 1984). In marginal land low plant density could give good results. Mbatani (2000) for example, found that with a plant density of 14 000 plants per hectare, 3.5 tonnes/ha of maize was found in the Northwest Province of South Africa. In contrast higher plant densities gave lower yields in marginal land (with moisture stress as a limiting factor) in Awassa, Ethiopia. With a plant density of 53 000 per hectare of maize, the yield found was only 2.9 tonnes/ha (Urage and Dauro, 2000). At a later stage during the growing season thinning was done to reduce the plant population. But in areas where moisture is a limiting factor, thinning at a later stage is not a solution because the plants, which were thinned out later, were depleting the limited moisture available before they were thinned out. This then can reduce the amount of moisture left for the plant (Laker, personal communication).

In Eritrea moisture availability is the most limiting factor for sustainable rainfed agriculture. Therefore it is proposed that appropriate planting density should be established and low plant density with relatively low input aiming at low production with minimum risk should be practised rather than high planting density with high probability of crop failure.

The use of artificial fertilizer should be adjusted according to the fertility status of the soil and the attainable yield as determined by climate (Rios and Weibel, 1984). Since fertilizer might not be available to farmers because of infra-structural or economic reasons, manure or green manure crops could be used to improve fertility. In addition some cultural practices like fallow and crop rotation could also increase production. Under rainfed agriculture crop yield could vary from 300 to 3000 kg/ha depending on management and inputs used.

5.3.1.3 Persistent weeds, pests and diseases

Successive planting of sorghum in the same area of land for longer period could result in a range of weeds that can compete for moisture and nutrients during the early stage of development. Most serious is the establishment of the semi-parasitic weed striga. This weed attaches itself to the roots of flowering plant mostly grasses. According to Gibbon and Pain (1985) such parasitic weeds have the ability of producing thousands of seeds and can stay dormant for many years. The damage to the plant is done before it emerges and when it is entirely parasitic on the roots. They have the capacity of reducing around 80% of the expected crop yield. This is a problematic weed in Eritrea and their preventive measure is through crop rotation.

The major pests that can attack sorghum includes shoot fly (*Atherigona varia soccata)*, stalk borer (*Chilo partellus, Busseola sorhicida)*, and (*Sesamina calamistis)* (Gibbon and Pain, 1985). Birds can also cause a considerable damage. The most important pest in Africa is the weaverbird (*Queleu quelea* L) which lives in large colonies and can attack mature sorghum or millet (Norman *et al.* 1984). In Eritrea the problem of bird attack is serious and farmers hire somebody to chase the birds and sometimes, to reduce the yield loss, farmers plant sorghum collectively.

There are many diseases which can attack sorghum and includes leaf spot, downy mildew, rust, anthracnose and blights (Rios and Weibel, 1984). There is not enough evidence to substantiate the level of loss from diseases, but the problem of rust is high in lowland Eritrea where the dominant crop is sorghum.

5.3.2 Requirements for Wheat production (Triticum aestivum L)

Principally wheat is a temperate crop but it can also grow in cool parts of the tropical and sub-tropical regions of the world. The grains vary from hard to soft, and from red to white. Attempts have been made to develop caltivars that can survive in sub-tropics and in higher altitudes in the tropics. As a result different varieties including a dwarf that can suit warmer countries (Ghana) have been developed. At the same time varieties that resist diseases (rust) have been developed to be grown in Kenya (Purseglove, 1986). In the cool highlands of Turkey wheat cultivars developed in cool areas of the former Soviet Union performed much better than the so-called "high yielding varieties" developed by CYMMIT (Winkelman; as cited by Laker, 1979). In an un-written presentation by an Egyptian soil scientist at the congress of the Egyptian Soil Science Society in Cairo in October 2000, it was mentioned that studies in Egypt showed that locally developed wheat cultivars gave better results than a "good" cultivar imported from Syria (Laker, personal communication). This further emphasises the importance of using cultivars that are adapted to (or have been developed for) specific environmental conditions.

At the same time varieties that resist diseases (rust) have been developed to be grown in Kenya (Purseglove,1986). New rust strains develop continuously which infest "rust resistant" cultivars. In rust prone areas, like the Western Cape province of South Africa, new wheat cultivars must, therefore, be developed continuously which are resistant to the new rust strains (Laker, personal communication). Selection of appropriate planting dates can in some areas minimize the rust problem (Khuvutlu &

Laker, 1993). In the latter study, it was found that rust was mainly a problem in crops planted late because of an efficient government ploughing scheme for small farmers (Laker, personal communication).

In Eritrea wheat is grown in the cool areas of the highlands. The main use of the grain is for bread and the crop residue is used as animal feed. Mostly it is grown under traditional, animal drown implement, with low inputs. However the Ministry of Agriculture, through the approach of collective farm project, is providing machinery and inputs as a loan to farmers and their fields are ploughed and planted collectively with the same crop (wheat, sorghum etc.) to facilitate management and other cultural practices (crop protection). The project has three years and so far the achievements are encouraging.

5.3.2.1 Climatic and soil adaptability for wheat production

Wheat has a wide climatic adaptability (especially temperature) but such adaptation must coincide with the selection of appropriate cultivars that can do well in a specific location. Therefore care should be taken during importing varieties in such a way that the new varieties should be developed under or for conditions similar to Eritrea. If local varieties have to be developed in Eritrea, They must be screened under the climates where they will be grown in farmers' fields.

Generally in East Africa, wheat can do well in areas with altitude ranges of 1600-3000 m above sea level, and it can be said that wheat can be grown under a variety of temperature conditions. It can be grown under high temperature provided that this does not coincide with periods of high atmospheric humidity. Wheat can give good yields on area with annual rainfall of 500-700 mm on heavy soils that can hold more water. For example in Kenya wheat yields best on annual rainfall of 250-500 mm on heavy soils (Purseglove, 1986).

Wheat can be grown on variety of soils, but fertile soils with reasonable drainage and good water holding capacity are preferred. The ideal texture for wheat production ranges from fine to medium with soil depth of 60-90 cm. The soil reaction or pH range of 6.0-7.0 is satisfactory. The crop needs high nutrient and has medium tolerance to salinity (Landon, 1991). Generally high yielding varieties require very fertile soils and high fertilizer inputs, especially nitrogen. Under such conditions they give good yields but under unfavourable conditions they perform very poorly. Therefore in such circumstances, varieties that tolerate the prevailing condition are better than high yielding varieties. In Eritrea breeding should focus to develop varieties that can perform well under the available soil conditions.

Wheat has an exceptionally deep root system and can tolerate subsoil compaction where crops like maize or cotton fail. In contrast wheat is very sensitive to soil crusting (surface sealing) and it is very difficult to get a wheat crop established on a soil that is prone to crusting (Laker, personal communication).

5.3.2.2 Cultural practices for wheat production

The land should be well prepared and levelled before planting and seeds can be sown on rows or broadcasted. This practice determines the seeding rate. For hand sowing, depending on varieties, seeding rate of 120-150 kg/ha is recommended. For tropical Africa the semi-dwarf varieties are suitable because of their short growing time but they require fertile soils and high fertilizer input. In Eritrea wheat is sown during cool season of June-July and harvested on December. Rotation of wheat with legumes and maize is good to consider, so that the N used by the crop can be easily replaced through N fixing ability of legume crops. Wheat responds well to fertilizer application, particularly nitrogen, phosphate and potash. The amount of fertilizer depends on nutrient content of the soil and climate.

5.3.2.3 Pests and Diseases

An important pest of wheat is stem borer (*Sesamia calamistis*). Burning the crop residue after harvesting and using resistant varieties could be used as a control measure.

Different diseases caused by fungus, virus and bacteria could attack wheat. The most common are the stem and leaf rust and smut and the steak and mosaic virus diseases.

The occurrence, severity and the consequent yield loss vary depending on the growth conditions as well as the cultivar used. To control such diseases seed dressing and using resistant varieties could be practised (Yayock, Lombin and Owonubi, 1988). In Eritrea, the author does not know the severity of such problem, and serious investigation is needed for the future.

5.3.3 Strategies for application of Land Suitability Evaluation Findings in Land Use Planning (the Sorghum and Wheat)

Table 5.1 summarizes the most important climatic and soil requirements for wheat and sorghum production. Such information is vital for allocation of certain areas of land for specific land uses because all land does not have the same potential to support the need of a certain land use.

Table 5.1 Climatic and soil requirements for sorghum and wheat production

Crop	Total growing period	Mean daily temperature for growth (°C) optimum (and range)	Day length requirement for flowering	Specific climatic constraints / requirements	Soil requirement	Sensitivity to salinity
Sorghum *Sorghum bicolor*	100-140+	24-30 (15-35)	Short day/day neutral	Sensitive to frost; for germination temperature must be >10 °C; cool temperature causes head sterility	Light to medium or heavy soils, relatively tolerant to periodic water logging pH 6-8	Moderately tolerant
Wheat *Triticum Spp*	Spring: 100-130 Winter: 180-250	15-20 (10-25)	Day neutral/long day	Spring wheat: sensitive to frost; winter wheat: resistant to frost during dormancy (>15 °C), sensitive during post dormancy period; requires a cold period for flowering during early growth. For both, dry period required for ripening.	Medium textured is preferred; relatively tolerant to high water table: pH 6-7	Moderately sensitive.

A strategy is required to approach land suitability evaluation. For the Eritrean situation two alternative strategies can be proposed. The choice of the strategy depends on the overall objective and on the available resources. The strategies are:

(i) Allocation of alternative crops for specific areas.

(ii) Allocation of alternative areas for specific crops.

The first strategy is applicable where the potential of a specific area is known and different land uses compete on the basis of their economic importance, the overall importance to the fulfilment of the general objective of the country, etc. For instance, in lowland (Southwest) Eritrea where the fertility of the soil is relatively high, the land uses (crops) that should be allocated must be those which are important for the attainment of the food security objectives of the country. The second strategy is employed to protect crop failure by applying the principle of selecting the right crop for the right area of land. For example sorghum is better adapted to relatively dry areas and heavy (vertic) soils than maize. The slow release of water from such soils causes less stress in sorghum than maize. So it is better to plant maize in areas where the availability of moisture is high and on soils that release water fast. Therefore, it is better to allocate areas with less favourable climate and soil for sorghum production. Planting sorghum on highly favourable areas and maize in less favourable area should be avoided, because the maize will not be able to handle the less favourable conditions well.

Wheat as a crop is adapted to a wide range of temperatures, provided the right cultivars are chosen for specific conditions. It can tolerate problems of clay soils and problems like compaction associated with fine sandy and silty soils better than maize. Areas with cool climates can be allocated to wheat production where sorghum (which requires warm climates) is not adapted. Generally it is not advisable to grow wheat in hot areas with maximum temperatures of more than 25°C.

In a country (like Eritrea) or area/region where arable resources are limited and production of maize, sorghum and wheat is required, the following strategy would thus be recommended: Reserve the higher rainfall areas and soils with easy water release (sandy to medium textured) for maize. This could be stretched to drier areas, provided that low planting densities and low fertilizer inputs are used (Mbatani, 2000). Allocate the warm, drier areas and/or more clayey soils with slow water release to sorghum. Allocate the cooler areas to adapted wheat cultivars.

Similar strategies could be used for other crop combinations.

5.4 Land qualities that should be assessed

The above types of strategies can only be employed when the requirements of the crop and land qualities of the area are known. FAO (1983) recognises 25 land qualities that can be assessed depending on the objectives of the evaluation (Appendix 4). The most important land qualities that should be assessed in relation to rainfed agriculture in Eritrea are as follows:

(i) Moisture availability
(ii) Nutrient availability
(iii) Rooting condition
(iv) Erosion hazard

5.4.1 Moisture Availability

This quality affects plants through the effect of moisture stress. Moisture stress occurs where the available water is below the needed quantity. The result will be wilting and finally total crop failure. In Eritrea such problem affects crops during the months of September-October when the crops are at a flowering stage. The erratic nature of rainfall calls for different strategies to avoid such crop failure. One way of doing this is to select short season varieties or to adjust planting dates. Most crops are susceptible to moisture stress during emergence or establishment and at the flowering stage.

Generally climate determines the availability of moisture in certain area, but soils and landforms are also important factors to consider. Different soils have different water holding capacities. Landforms are also influencing the ability of crops to use the available water or not. For example in steep areas, because of high runoff, the amount of moisture infiltrated into the soil is small and as a result the available water for the crop is limited, but in areas with gentle slope the available moisture is high. In Eritrea, where the amount of rain is small, landforms that facilitate infiltration of almost every drop of rain into the soil are preferred to decrease the probability of crop failure by increasing the available water in the root zone. The total amount, variability and distribution of rain are important factors. The amount of water readily available for crops is the difference between total rainfall received and the rate of evapo-transpiration. Therefore, it is obvious that the same crop grown in warm areas of Eritrea needs more water than in cooler areas.

Both sorghum and wheat require 460-650mm of water per growing period (Landon, 1991). But sorghum can survive in areas with as little as 380mm moisture provided the soils are clay or sandy-clay to hold more water. Based on the amount of rainfall received, sorghum can grow in all agro-ecological zones of Eritrea except in the semi-desert zone where the rainfall is less than 200mm. In some relatively dry zones only short season varieties can be grown. Wheat on the other hand can only grow in moist highland and moist lowland but moisture is only one factor. Others like soils, temperature regime, etc. restrict the ability of wheat to grow in the moist highlands of Eritrea. This indicates that amount of rainfall alone cannot determine the final suitability of an area for specific crop. Other factors such as variability, distribution, temperature regime, soil type, and landforms should be assessed before one decides on final suitability. For techniques and methods of assessment of these variables, reference should be made to Berhane (2000).

5.4.2 Nutrient Availability

This is one of the three most important qualities that determine successful rainfed agriculture. It refers to the ability of soils to supply plants with important nutrients for growth. The parent material in which the soil is formed and the ability of plants to use the existing nutrients determine the fertility of the soil. The supply of nutrients can be presented into ways i.e. (a) nutrient availability (the ability of soils to supply nutrients) and (b) nutrient retention (the ability of soils to retain nutrients against leaching).

In the Eritrean situation the distribution of fertilizer is limited and the buying power of farmers is low. The main focus should, therefore, be on the natural fertility of soils and ways to improve it through addition of manure and fallowing (resting). To determine the fertility status of a soil, it is important to conduct chemical analyses. On the other hand it is not economical for each farmer to do chemical analysis of his/her field. A quick analysis of soils can give some indication on the fertility status of soils, however. This includes checking the pH of the soil, i.e. nutrient availability is higher in soils with the pH range of 6.0-7.5 and decreases at both high and low values of pH (FAO, 1983). The amount of fertilizer to be added is determined by the fertility status and the attainable yield and varieties. For example semi-dwarf wheat gives high yields but requires very high fertilizer inputs and ideal soils for its successful production (Laker, personal communication). Therefore, such varieties are not applicable for Eritrea, but varieties that are developed for/under the Eritrean situation should be selected.

For the Eritrean situation it is proposed to have a well-established soil laboratory at a national level that can assist in determining the soil fertility. Generally there are certain indicators that show favourable or unfavourable characteristics for high soil fertility. According to Young (1976) these characteristics are as shown in Table 5.2.

Table 5.2: General conditions for soil fertility (Young, 1976)

Soil property	Conditions favouring high soil fertility	Conditions unfavourable to high soil fertility
Soil depth	>150cm	<100cm
Texture	Loam, sandy clay loam, sandy clay, clay (if structure and consistence favourable)	Sand, loamy sand; heavy clay
Structure and consistence	Moderate to strong, fine or medium structure; friable consistence	Massive, or coarse structure, with very firm consistence
Moisture conditions	Free drainage with good moisture retention	Substantial drainage impedance; low moisture retention and rapid permeability
Plant nutrients	High level	Low level
Cation-exchange capacity	Medium to high levels (>20 me/100g in topsoil, >10 me/100 g in low horizon)	Low level
Weatherable minerals	Present within 200cm	Absent above 200cm
Reaction	Generally pH 6.0 to 7.5, but varies with crops	<6.0 and >7.5
Salinity	Low soluble salts and exchangeable sodium	High soluble salts and exchangeable sodium
Organic matter	Adequate in relation to levels under natural vegetation	Low levels

5.4.3 Rooting Condition

This quality refers to the effective depth a root can reach to extract nutrients and moisture and at the same time to anchor the plant firmly in the ground. If the growth of the root is restricted at relatively shallow depth by rock, hard layers like petroplinthic, petrocalcic, etc. horizons, dense clay, a water table, etc. then the development of the plant will be limited. According to Landon (1991) both sorghum and wheat have a deep root system i.e. 100-200cm and 120-150cm respectively. These are, in fact, under estimations of the rooting depths of grain crops. Boedt and Laker (1985) found that in deep fine sandy soils wheat and maize roots extract as much water at 250cm depth as in the topsoil. In California it was found that maize extracts water up to 300cm depth from Yolo silt loam soils (Laker, personal communication). Therefore the best soils for these crops are deep and easily accessible to roots. Deep soils have high plant extractable water storage capacities.

In South Africa most of the soils in which wheat is grown commercially are **very** shallow (<40cm). Success is achieved with low planting density/low input strategies and by selecting adapted cultivars. In the Eastern Free state area of South Africa extension officers and plant breeders were upset because the farmers refused to stop planting two old cultivars in favour of new "better" ones. Subsequent trials on different soils showed that **only** the two old cultivars, used by the farmers, gave reasonable yields on the shallow soils, which covered more than 50% of the wheat producing lands. The new cultivars did well only on good, relatively deep soils, which are scarce in the area. So the indigenous knowledge of the farmers was better than the knowledge of the extensionists and breeders in regard to optimum utilization of problem soils by using adapted cultivars (Laker, personal communication). Similar selections are possible for other crops, including appropriate rootstock selection for growing fruit trees, vines, etc.

5.4.4 Erosion Hazard

If the above three qualities, i.e. moisture availability, nutrient availability and rooting condition are suitable for crop production, efforts should be focused on avoiding human-induced soil degradation, especially water and wind erosion. Erosion will reduce the volume of the soil, which can result in low nutrient content (especially since the fertile topsoil is removed), shallow soils and low water holding capacity of the soil. The final result would be poor soils with low production capacities. The assessment for erosion hazards should involve two aspects, i.e. the susceptibility of land to erosion and the resulting loss in productivity of the land affected (FAO, 1983). During assessment factors like climate (rainfall intensity), soil erodibility, slope (angle and length) and vegetation factors should be assessed. Different assessment methods are known, ranging from a large number of international methods like the USLE (Universal Soil Loss Equation) and the FAO Soil Degradation Assessment (FAOSDA) methodology, to a regional methodology like the SLEMSA (Soil Loss Estimator for Southern Africa) to local methods based on slope and observed present erosion (FAO, 1983).

There is a tendency in developing countries to use USLE, or an adaptation of it, as basis for estimating the erosion potential of areas. It must always be kept in mind that differences between different regions of the world are so big that USLE cannot simply be used in its original form. Even in the USA, where the USLE was developed, it has been found that it is applicable only to the north-eastern corner of the country (where it was originally developed) (Laker, personal communication). Consequently RUSLE (revised soil loss equation) was derived from it for the Midwest of the USA. Soils (especially in regard to parent material) and climates in Africa differ so drastically from those in other continents (except Australia) that USLE or RUSLE cannot be used in African countries without major adaptations.

After drastic modification and adaptation USLE (or RUSLE) could be adapted for Eritrea. This method has some shortcomings, however. Its main problem is the vast amount of data it requires and the difficulty of measuring values for the various factors. This could be a major problem in Eritrea because of shortages of experts, know-how and capital to run the research. For modification one needs experiment stations that develop local standards, which need more money and other resources which Eritrea cannot afford at the current stage of development.

Furthermore USLE was designed for predicting soil loss from a given field, as a basis for selection of conservation practices for a specific site. It was not intended for predicting soil loss from watersheds or large areas.

As a first approximation a more viable approach may be the very simple empirical one used by D'Huyvetter and Laker (1985) in the former Ciskei homeland of South Africa. By means of aerial photographs, slope and soil studies and studies of present erosion in pilot areas of different regions they derived simple equations to predict the erodibilities of different soils under cultivation.

In Eritrea, there has been some work done on the estimation of soil loss in specific research areas (Afdeyu, Eritrea). It is not known what methods were used and the current activity of the research.

For the current Eritrean situation, it is proposed that local knowledge should be used to estimate present erosion through observation and asking local farmers about the state of the soil some 5-10 years ago. Some indicators, e.g. presence of many stones in highland Eritrea, exposure of plant roots, etc. could be used to explain the actual situation of erosion in a specific area. In order to conserve moisture different conservation measures should be planned and implemented (with full participation of local farmers) in order to conserve moisture and the soil.

Table 5.3 shows some of the important land qualities and their corresponding land characteristics that are used to measure land quality for rainfed agriculture. Through collecting information on the quality of the land, one can easily compare with the requirements of the crop. Rating of the area can follow, depending on its capacity to support specific crop.

Table 5.3: Land qualities for rainfed production and their corresponding land characteristics that are used to measure the quality (From FAO, 1996)

Land quality	**Land characteristics used to measure the quality**
Availability of energy	Sunshine hours in growing season, Temperature regime
Availability of water	Evaporative demand set against rainfall, soil water storage and rooting.
Conditions for ripening	Period of successive dry days with specified sunshine and temperature
Climatic hazards	Frequency of damaging frost, hail or winds during growing period
Sufficiency of oxygen in the rooting zone	Soil drainage class, depth to water table, texture, structure and consistence
Sufficiency of nutrients	Soil nutrient level, pH, organic matter content
Erosion hazard	Rainfall and wind erosivity set against soil cover, slope angle and length and soil permeability
Toxicity	Levels of soluble Al and Fe; pH

5.4.5 Irrigated agriculture and extensive grazing

The above-mentioned qualities are exclusive to rainfed agriculture only and depending on the scale, objectives and economic status of the land user, other qualities could be assessed. On the other hand different land qualities are used to evaluate the capacity of an area of land for irrigated agriculture and extensive grazing. For example the most important qualities as far as extensive grazing is concerned are availability of pasture and drinking water. The qualities that should be assessed for evaluating irrigated agriculture and extensive grazing are presented in Appendices 5 and 6 respectively.

5.5 Comparison of land use with land

This stage of suitability evaluation is crucial where the qualities of the land are compared with the requirements of crops. Generally, this stage has three main activities that should be performed before one decides on the final suitability rating. These are physical matching of the crop requirements with land qualities, environmental impact of the use, and economic feasibility and social acceptability of the use by the community concerned.

5.5.1 Physical matching of land use with land

This refers to the physical comparison of the requirements of the proposed land uses with the qualities of the land (FAO, 1976). This could be done by checking measured values for each land quality or characteristic against the class limit or by allocating each land unit to its land suitability class according to the most severe limitation. Sometimes one limitation is sufficient to render the land unsuitable for the proposed use. For example, for maize production, it is of no use having level land and sufficient rainfall if the soils are highly saline (FAO, 1996).

In cases where the land is rated unsuitable, different measures could be employed to improve the suitability rating of the land. One way is to modify the land use type so as to overcome the limitations. For instance, if suitability has been downgraded because of erosion hazard, a new land-use type could be designed with the addition of contour-aligned hedgerows or other soil conservation measures. Another example is that the introduction of fast maturing varieties could be helpful to overcome the problem of production reduction in areas with a short rain season.

Another possibility is to improve the land itself. Inputs which can bring about relatively permanent improvements in the characteristics of the land could be used. Terracing of a steep land can improve the quality of the land for a certain kind of use. Improvement needs capital for its initial construction and maintenance, so it should be considered during suitability evaluation.

5.5.2 Environmental consequences of the proposed use

Environmental impact of the new land use should be considered during the process of comparison. Such effects can be divided into two, i.e. on site-effects (effects on the land on which the changes are implemented) and off-site effects (effects on another area of land) (FAO, 1976). On site-effects may include erosion and degradation of the land and measures should be taken to prevent such hazards. The off-site effect, on the other hand, refers to problems which can arise indirectly, e.g. a malaria problem that may result from the construction of a dam near a settlement; effects of bush clearance that can increase runoff on down stream river flow, etc. It is very difficult to reverse such damages; the best thing to do is to predict such problems before they occur and take measures to prevent them.

5.5.3 Economic feasibility and social acceptability of the use

Economic and social analysis is another important part of comparison and deals with economics, i.e. the input-output relationship and the overall return to the land user should be estimated before decisions on suitability is made. Social analysis refers to the acceptability of any change by local people. If community members do not approve the proposed land use, it is difficult for its continuity. One of the FAO Framework (1976) principles states that suitability should be done relative to the physical, economic and social condition of the area concerned.

5.6 Land suitability classification

This is the most important part of the evaluation process but it also depends on how all the other parts of the evaluation process were done. There are different ways of determining the suitability ratings, depending on the physical environment, but this must not be taken as final because others like environmental impact and socio-economic consequences should also be considered before the final suitability is decided. Rossiter (1994) proposed three methods of determining suitability ratings depending on the physical environment only, these are:

I. Maximum limitation method

II. Algebraic combinations

III. Subjective combination

5.6.1 Limiting condition

This method puts more emphasis on the most limiting factor for successful production and is sometimes known as the "law of minimum" in agriculture, which states that crop yield will be determined by the plant production factor which is most limiting (FAO, 1976).

This procedure should always be followed when there is an assessment of N (not suitable). For instance, if the rooting depth is a limiting factor for a certain LUT, a land mapping unit with shallow soils, but ideal temperature regime, moisture availability, etc. will have an overall suitability of not suitable, because the proposed crop can not grow in a shallow soil.

The advantage of this method is its simplicity. The disadvantages, on the other hand, include its failure to take account of interactions and it does not differentiate between land areas with several limitations and those with only one, as long as the maximum limitation is the same (Rossiter, 1994).

5.6.2 Algebraic combination

The overall physical suitability of a land area for a LUT is computed according to a formula based on the individual factor ratings. For instance, the average of the LQ levels, or a weighted average giving more weight to more severe limitations, or some rule similar to "3 moderate limitations are equivalent to 1 severe limitation". It can be said that this is a more flexible version of the maximum limitation method.

5.6.3 Subjective combination

This is an *ad hoc* combination, which depends on subjective judgement of the suitability rating and prior knowledge of the ecology and technology of the land utilization type is important. So the evaluator can compare to the qualities of the land subjectively.

There are mainly two disadvantages of this method. Firstly, two evaluators may not have the same judgement on one issue. Secondly, it needs very experienced evaluators who have a good knowledge of all crops. If the evaluator is experienced, the system is very fast and this can be the main advantage (FAO, 1976).

For the Eritrean situation the limiting factor approach can give more satisfactory results than the other two. This is mainly because the remaining two needs experienced experts (which Eritrea doesn't have currently) and certain results of research. In Eritrea the most limiting factor is the low availability of moisture, so every proposed land utilization type should be related to the conservation of water and effective use of available water.

5.7 Presentation of results

The overall objective of land suitability evaluation is to classify a certain area of land according to its suitability for a specific use. The final result, therefore, should include maps, tables and a supporting report. There are two ways in which a mapped suitability could be presented. Firstly, the base map that was used for field survey can be used as a final suitability map but this is not recommended because of problems of neatness, so another map with the same scale is preferred. The second way is by compiling different suitability maps, i.e. one for each kind of land use. This way, if coloured maps are used, is effective in attracting readers and map users. On the other hand it is more expensive than the first method.

As far as tabular presentation is concerned, suitability could be presented for current (without major improvement) and for potential (after major improvement) situations (Tables 5.4 and 5.5). During presentation for potential suitability, all proposed improvements, including their financial demands, should be indicated in the report. This helps decision-makers to decide whether a particular improvement is more applicable than another is.

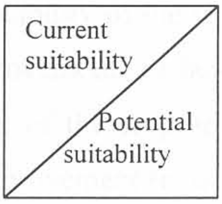
The supporting report should specify all the procedures used, assumptions made and objectives considered. It must avoid using scientific words and should be presented in such a way that all concerned people should read it and understand it easily. A well-written report that can only be understood by specialists (e.g. soil scientists) is useless for other parties involved in land use planning. Therefore, a report should be written in simple words that could be easily understood by extension workers and land users.

Table 5.4: Tabular legend for current suitability (from FAO, 1976)

Land mapping unit	Kinds of land use				
	A	B	C	D	E (etc.)
1	S1	S3	N2	S1	S2
2	S2	S1	S2	N1	N2
3 (etc.)	S3	S1	N1	S3	S1

Table 5.5: Tabular legend for potential suitability (from FAO, 1976)

Land mapping unit	Kinds of land use	
	A	B (etc.)
1	S3m / S2	N2e / N1e
2 (etc.)	N2m / S3s	N2e / N1e



5.8 Conclusion

Land suitability evaluations can be employed for two specific reasons, i.e. to find a suitable area of land for a specific land utilization type or to allocate a suitable land utilization type to a specific area of land. These two strategies can be used alternatively, depending on the circumstances of a specific country or area. The latter strategy needs comparison (economic) between two or more land uses before one decides on the use of a particular land. The more profitable use, whether poultry or dairy farms or horticultural crops or grain crops, will be considered. So the determining factor in choosing a strategy is the objectives of the evaluation. For example, if the objective of a country is to find areas of land for specific commercial crops (tea or coffee) or to grow some selected grain crops (wheat, sorghum or maize) in order to achieve self-sufficiency in food, then the former strategy is suitable. This strategy gives priority for selected crops to be grown in more suitable areas of land but it also needs strategic allocation of land for a specific crop. For example it is not wise to allocate areas with enough moisture and good soil conditions for sorghum and areas with less available moisture and relatively less fertile soils for maize, but the opposite will give good results. This is because naturally sorghum can do well in areas of less moisture and relatively poor soils than maize. Such strategy is suitable for Eritrea today because the main objective of the country is to be self sufficient in food by growing selected crops on suitable lands.

In order to reach a final suitability ratings, it is important to know the requirements (climatic, soil, landforms, etc.) of the proposed crop and qualities of each specific area of land. Through the process of physical matching the suitability rating of an area can be decided for a specific use. But this is not a final suitability. Others, like environmental consequences, economic feasibility and social acceptability of the use must be evaluated before reaching on final suitability rating. Improvements of land qualities can be proposed in order to bring both the requirements of the crop and qualities of the land in harmony. The cost involved during land improvement (major improvement) should be considered during evaluation. Land suitability evaluation is a dynamic process in a sense that when circumstances change, the objectives can also be changed. As a result different uses can be proposed for certain area which is currently under a specific use.