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Development of Soil Suitability Ratings Index for Crops in the North – East of Libya Using Geographic Information System

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Abstract

Agriculture production faces a great challenge for the coming decades which is the food security for the ever-increasing world's populations. The key role in sustainable agriculture production can be played by sustainable soil uses and management. Land evaluation for specific purpose is an important tool for land use planning. A number of land evaluation techniques have been developed to assess land for different uses. The parametric approach is one that combines various soil and site properties (parameters) that are believed to influence yield using mathematical formula. The Storie Index Rating was an early attempt at quantitative land evaluation and an example of parametric approach. The system has been widely applied around the world, for example, It has been used in California, mainly for irrigated soils (Kudrat and Saha, 1993). In addition, it was adapted in Libya. The Libyan modified index rating takes into account local conditions to determine the properties included. Local experiences were used to classify the soil suitability (Mahmoud, 1995). The rating was taking into account eleven soil properties to produce an overall rating. This paper modified the productivity rating and produce computerized model which uses spreadsheet model for suitability analysis and integrates the results in geographic information system (GIS) environment. The results show that Barley is the most suitable crop with 42 % of the area is very high suitable and about 18 % is not suitable for barley. Whereas maize is about 29 % is high suitable in that soils of the study area, and less than 25 % is not suitable. GIS allow modelling, running a range of soil use scenarios and data manipulate so that the optimal soil use can be identified to achieve sustainable development. In addition, it allows the comparison between different crops to select the most appropriate to local conditions and development goals**.** This paper is part of series research papers which uses concepts developed and applied in different area of Libya.

Keywords: Land- Crops- Suitability- GIS- Food security- Land use- Sustainability.

1. Introduction

The food supply should be granted to 6 billion inhabitants on 2000 and estimated 8 billion people in 2025. Food supply shortages occurs in arid and semi-arid zones where a land degradation and desertification are the main obstacles facing sustainable agriculture. A determination on how to use best the lands in the North-East of Libya for sustainable agriculture and environmental protection is prerequisite. Therefore, land evaluation is vital process to aid the decision-making process for agricultural development. The principal purpose of land evaluation is to predict the potential and limitations of land for changing use. Land evaluation is the process of predicting land performance over time according to specific types of use. These predictions are then used to guide strategic land use decision making (Rossiter, 1996; Van Diepen et al., 1991; Nwer, 2005).

Several land evaluation methods, concepts, and analytical procedures have been developed since 1950. The focus of these evaluations has shifted from broad to specific assessments. This has led to a diversity of approaches, ranging from straight forward soil survey interpretations to more sophisticated, multidisciplinary, integrated, regional studies, and to the application of simulation techniques (Van Diepen et al., 1991; Nwer, 2005).

Some methods value the degree of suitability of resource properties, while others place more emphasis upon the possible limiting factors imposed by environmental conditions. Qualitative criteria are used in some methods while others are more quantitative. Some systems group land into a series of levels of importance (order, class, subclass…etc.). Other systems use mathematical formulae so that final results are expressed in numerical terms (Nwer, 2005).

Parametric approach has been used in land evaluation. The parametric approach combines the various soil and site properties (parameters) that are believed to influence yield using mathematical formula. Some parametric systems are simple whilst others can be extremely complex. Some have been widely accepted, usually because they have been incorporated into legislation on taxation, and others have been ignored (McRac & Burnham, 1981). The best-known multiplicative system for rating the quality of land is the Storie Index Rating (Storie, 1978). Mahmoud (1995) developed a parametric productivity rating for Libyan soils. Eleven soil properties were used to determine the productivity index rating. This method was adapted from the Storie Index Rating, taking into account the local conditions to determine the properties included. Local experience was used to classify the soil suitability. The method is attractively simple and accurate (Nwer, 2005). The method involves the construction of look up tables and the transfer functions and subsequent calculations of suitability. These processes are time consuming and are liable to errors. Therefore, there are a great number of benefits to be gained in automating the calculations of the index rating (Nwer, 2005).

Geographic Information Systems (GIS) is an effective tool for land evaluation and soil use planning. It is a combination of spatially referenced data, appropriate computer hardware and software, and users competent to employ the data and technology to solve problems. GIS is quickly becoming the data management standard in planning the use of land and natural resources (Martin and Saha, 2009). Virtually all environmental issues involve map-based data, and real-world problems typically extend over relatively large areas. There is no doubt that computer systems and GIS allow land evaluation to be performed more efficiently; they limit the margin for human error, and save time and cost (Kalogirou, 2002). However, it is certainly correct that the fullest benefit of this technology can only be realised when it is practical and accessible. Automated land suitability for crops in countries where the information technology is in its very early stages, should be made especially user-friendly and accessible for the average computer user (Rossiter, 1989). This is the case in Libya, where, it must be noted that levels of information technology penetration are still relatively low. Therefore, the need for a practical automated land evaluation tool in Libya is apparent and needs to be taken into consideration.

The parametric approach combines the various soil and site properties (parameters) that are believed to influence yield using mathematical formula. Some parametric systems are simple whilst others can be extremely complex. Some have been widely accepted, usually because they have been incorporated into legislation on taxation, and others have been ignored (McRac and Burnham, 1981). The Storie Index Rating was an early attempt at quantitative land evaluation. It can be appreciated that there is considerable value in being able to produce a number, ranging from 1 to 100, which expresses land suitability for one or more specific crops. The system has been widely applied, for example Leamy (1973) described how it has been used in New Zealand to aid farm valuation assessment and Lal (1989) applied a modified Storie Index to rate the productivity of sixty-four benchmark soils in India. In this Indian study the rating was on the basis of four factors; characteristics of the physical profile, surface texture, slope and a group of other factors such as drainage, nutrient status and erosion

This paper is part of series research papers which uses concepts developed and applied in different area of Libya (Nwer, 2005; Nwer, 2008; Nwer et al, 2013). The development of this tool applied by the author to soil productivity model using GIS based on productivity index which was developed in Libya for two main purposes: the ease of using soil productivity index and to compare this methodology with other method which uses FAO methodology.

2. The Study Area

2.1. Location

The study area is located in the strip of the coastal territory and Jabal Akhdar Upland bounded by the following coordinate's lat 31° 30 - 33° 00' N; long 19° 50 - 22° 45' E. This area of the country is known as North East and includes the Benghazi region and the Jabal Akhdar highlands Figure (1).

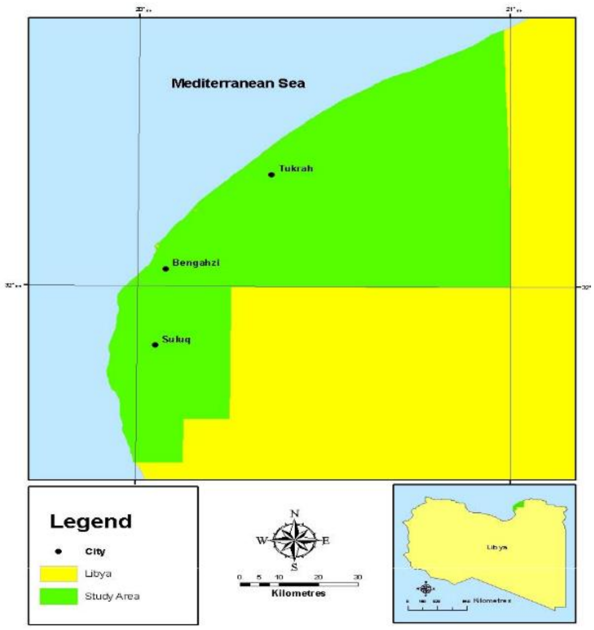

Figure (1) The location of the study area

2.2. Climate

The study area is situated in a Mediterranean type climate, in the belt of subtropical alternate atmospheric circulation. In the summer the climate is determined by a stable high-pressure zone situated over the Mediterranean Sea, i.e., by the Azores maximum spur with descending tropical air currents. In the autumn-winter-spring period, climate conditions are determined by the cyclonic activity of the ascending air masses in the temperate latitude zone. The mean air temperature in winter is two or three times lower than the summer. The amount of total rainfall precipitations from October to March is 85-90 per cent of the annual precipitation, its maximum evidently being in winter). The contrast in seasonal climatic indices increases due to two factors: orographic (Atlas Mountains), and baric (the high-pressure zone in summer) (Selkhozpromexport, 1980; Mahmoud,1995).

The climatic conditions in the study area are unstable and depend on the distance from the sea and the altitude of the territory. Further inland, the mean annual air temperature increases, while the precipitation amount decreases. With an increase of absolute elevation in the Jabal Akhdar Upland, the mean annual air temperature drops abruptly and the amount of precipitation increases. The orographic temperature gradient equals 3.8°C, that of precipitation being 345 mm.

2.3. C. Soils

Soils and their characteristics in the study area are affected to great extent by the nature and conditions in which these soils were formed. Generally, aridity is the main characterises of such soils. Most of these soils are undeveloped or partly developed. Soils in the study are classified in accordance with US Soil Taxonomy as shown in Figure (2). Aridisols and Entisols are the main soil order in the study area (Mahmoud,1995; Nwer, 2005).

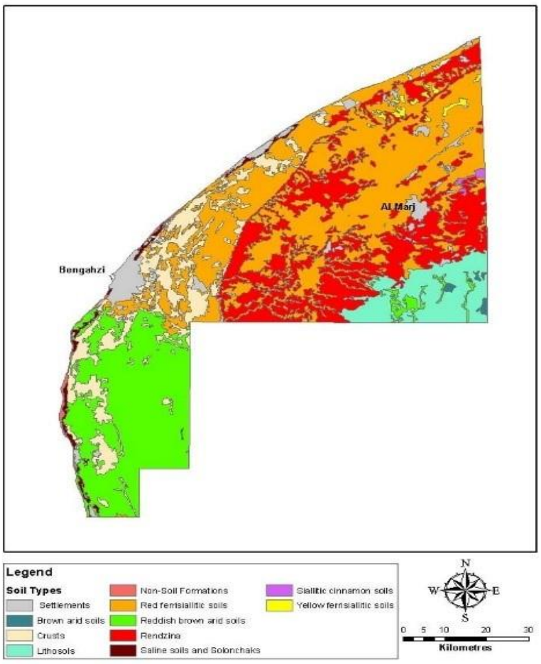

Figure (2) Soil Map of the study area

3. Material and Methods

3.1. Soil Productivity Index

The productivity index rating which has been developed by Mahmoud (1995) was applied to produce a productivity rating index in as follows:

- Eleven soil properties were Selected to produce an overall rating. The eleven soil properties were used to determine the productivity index rating (SPI) as shown below in the following box.

S P I = (A1×A2× A3×A4 A5×A6 ×A7×A8×A9× A10× A11)× 100

A1 = soil texture
A2= Soil compaction
A3= Soil Depth
A4= Water table level
A5 = Internal soil drainage
A6 = Soil Salinity
A7 = Exchangeable sodium percentage
A8= Soil reaction,
A9= Calcium Carbonate percentage
A10 = Soil Erosion
A11 = Soil slope

- Each soil property was given a different value between 0-1 depending on the effect of that factor on agricultural production according to previous studies and experience in Libya. The results are calculated to produce suitability classes Table (1). This method was adapted from the Storie Index Rating, taking into account the local conditions to determine the properties included. Local experience was used to classify the soil suitability.

Table (1) Productivity rating and suitability classes

Productivity rating %	Classes
0-20	Not suitable
20-40	Marginally suitable
40-60	Moderately suitable
60-80	Highly Suitable
80-100	Very High Suitable

(**Source:** Ben Mahmoud, 1995)

3.1. Soil Productivity Analysis using GIS

The ability to integrate data within GIS was used, bringing together data from different sources, formats, and scales and making them compatible with each other. To facilitate the execution of soil productivity model the following steps have been conducted Figure (3):

- compile all sources of data ((soil survey data, soil map, and location map);
- relational database design and normalisation including GIS design;
- the suitability analyses were executed in spreadsheet model.

- prototype construction and classification of thematic map layers.

The data and information were based on soil survey for the study area and available digital soil map for Libya (Selkhozpromexport, 1980). The soil productivity index was calculated to all the selected crops in spreadsheet model and exported to GIS to be mapped and to calculated the areas cover by each productivity class construct selection indices.

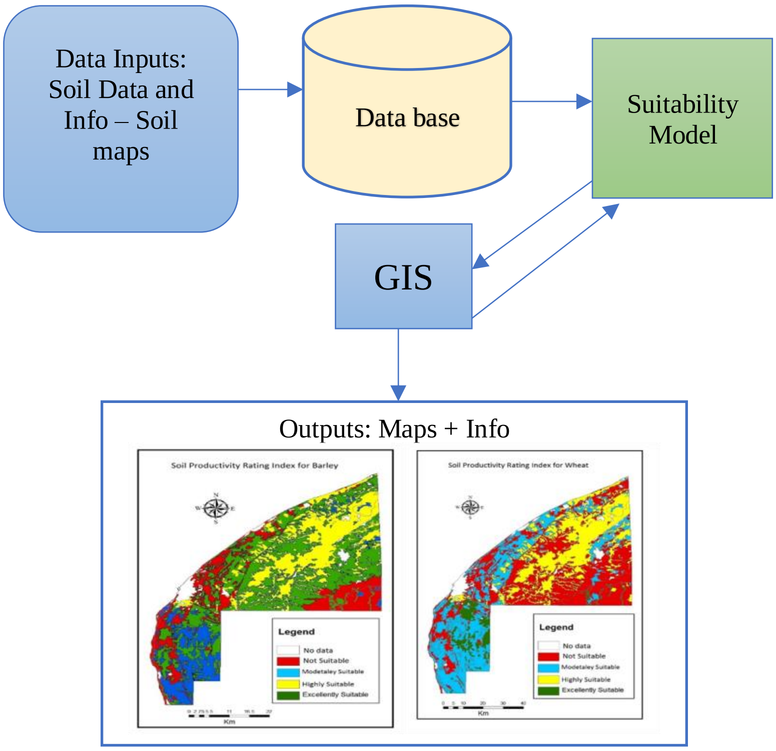

Figure (3) Process of Producing Soil productivity ratings

4. Results and Discussion

4.1. Soil Productivity Ratings for selected Crops

The soil productivity was conducted to wheat, barley, wheat, maize, and sorghum. The critical values for productivity ratings for each soil use were based upon available publications in agricultural research in Libya. The results revealed that. The analyses and calculations were conducted in spreadsheet model and integrated to GIS environment. The outputs of the suitability analyses were mapped on GIS to spatially represent the soil productivity ratings. Six maps were produced and area calculation for each suitability class were preformed Figure (4) to Figure (9).

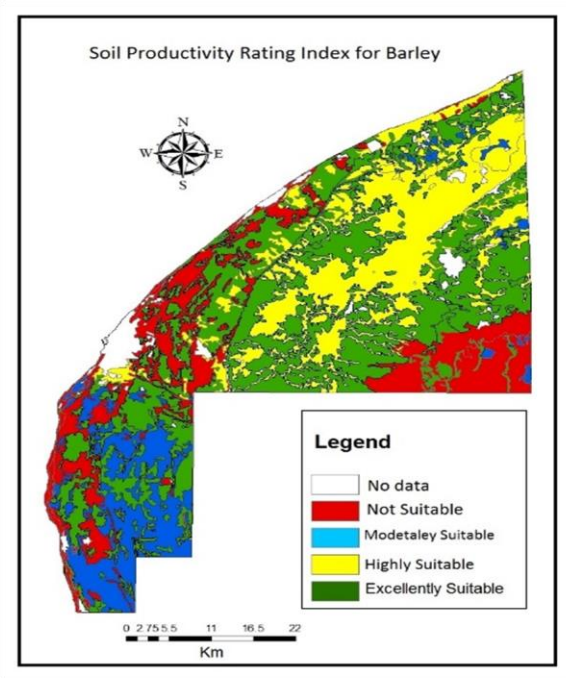

Figure (4) Soil Productivity Rating Index for Barley

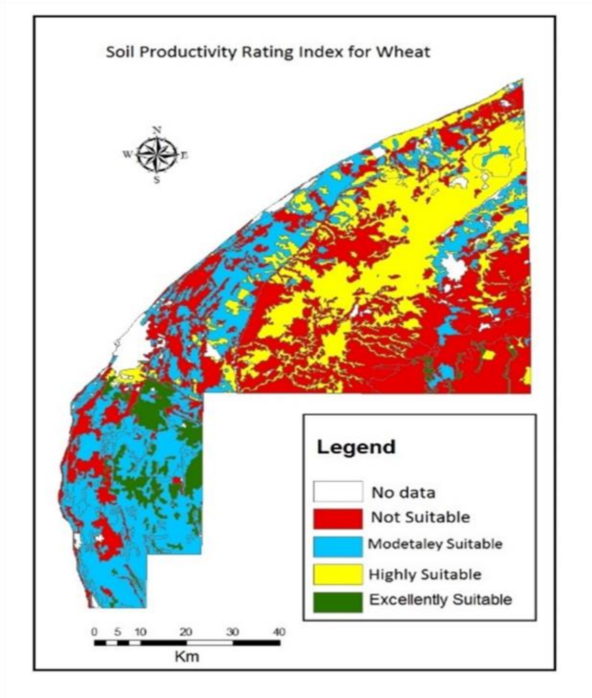

Figure (5) Soil Productivity Rating Index for Wheat

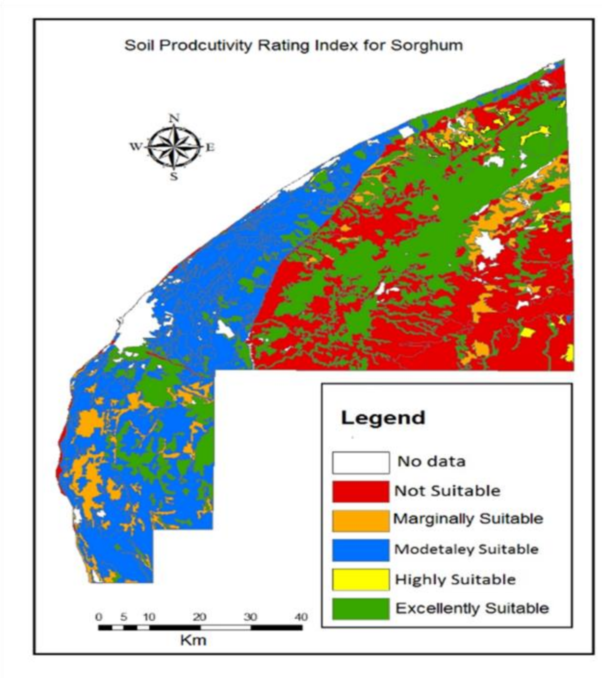

Figure (6) Soil Productivity Rating Index for Sorghum

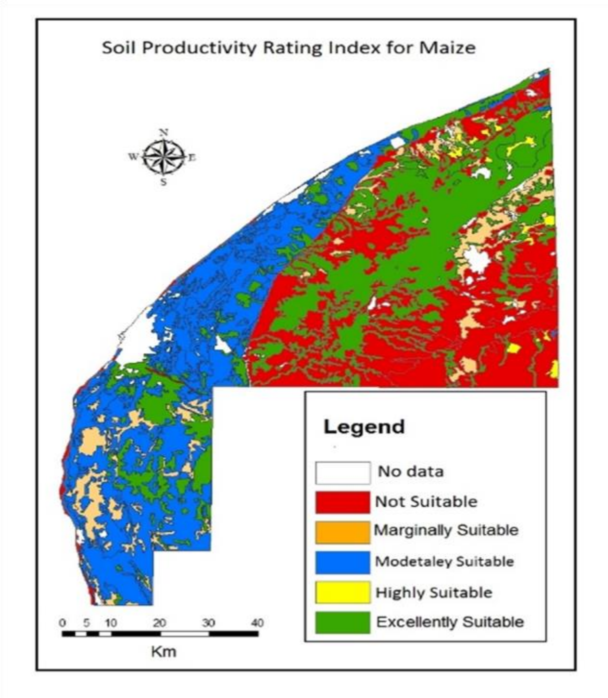

Figure (7) Soil Productivity Rating Index

4.2. Soil Productivity Ratings for selected crops

The soil productivity of each soil use was determined. By using GIS capability in terms of mapping spatial distribution and area calculations, it was possible to compare between different soil suitability classes for the selected crops. GIS allowed visual assessment of the different alternative of soil uses. The GIS also enable users to compare different scenarios. Table (2) show the outputs of the soil productivity index and the area covered by each soil productivity class of every crop.

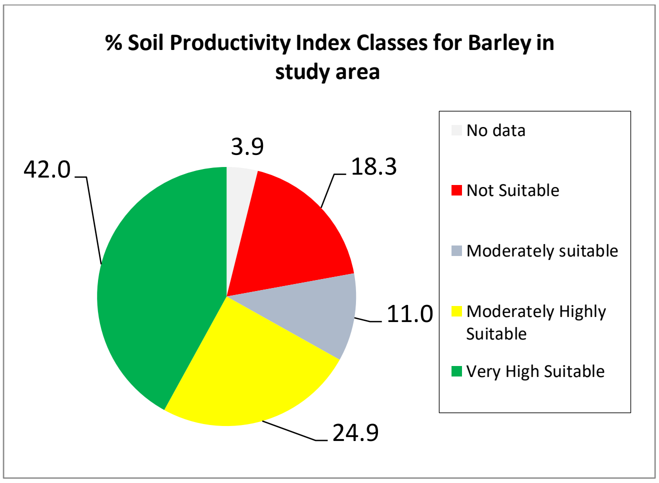

Figure (8) % Soil Productivity Rating Index classes for Barley

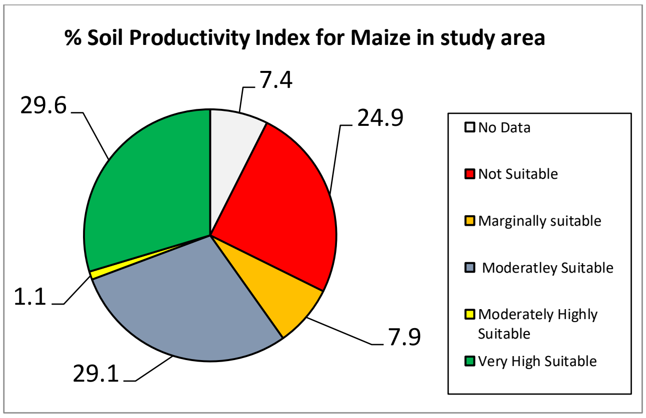

Figure (9) % Soil Productivity Rating Index Classes Maize

5. Conclusion

There is no doubt that computer systems and GIS allow land evaluation to be performed more efficiently; they limit the margin for human error, and save time and cost. In addition, the added value of such systems is that different scenario can be run and thematic output can be produced accordingly. This allow a wide range of suitability analysis and the identification of the sensitive soil attribute which effect agricultural production greatly.

The outputs from this study confirms the importance of GIS and automated land productivity index in Agriculture development. The results show that Barley is the most suitable crop with 42 % of the area is very high suitable and about 18 % is not suitable for barley. Whereas maize is about 29 % is high suitable in that soils of the study area, and less than 25 % is not suitable. Therefore, emphasis can be given to such criteria in terms of more data collection and focus. The most important aspect of using GIS is that it can be a tool to support decision making for competitive soil uses. This can give robust tool that allow decision makers to consider a range of alternative soil uses for optimal utilisation of available natural resources.

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تطوير مؤشر تقديري لدرجة ملائمة التربة لإنتاج المحاصيل فى شمال شرق ليبيا باستخدام نظم المعلومات الجغرافية

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الملخص

يواجه الإنتاج الزراعى تحدي كبير في العقدين القادمين يتمثل في الأمن الغذائي لسكان عالم يتزايدون بشكل مضطرد. لذلك يمكن ان تلعب إدارة استعمال التربة لانتاج المحاصيل بشكل مستدام دورا رئيسيا في التنمية الزراعية المستدامة. لذلك فأن تقييم الاراضي يمكن ان يكون أداة مهمة لتخطيط استعمال الاراضي، وقد تم تطوير عدد كبير من التقنيات والطرق والمناهج لتقييم الاراضي لعدد من الاستخدامات. وتعتبرالطريقة العددية إحدى هذه الطرق لتقييم الاراضي، وهي تلك الطريقة التي تأخذ في الاعتبار عدد من خصائص التربة والموقع (مؤشرات) والتي يعتقد بانها ذات تأثير على إنتاج المحاصيل باستخدام و تطويرمعادلات رياضية مبسطة.

يعتبر مؤشر ستواير من المحاولات المبكرة لتقييم الاراضي بشكل عددي ومثالا لتقييم الاراضي بالطريقة العددية. وقد تم استخدام هذا المؤشر بشكل واسع في مختلف انحاء العالم. كما تم تطويره وتحديثه بليبيا ليأخذ في الاعتبار الظروف المحلية وتحديد خواص التربة التي يمكن ان يحتويها المؤشر. واستخدمت التجربة المحلية لتصنيف ملائمة التربة بالإضافة إلى تحديد إحدى عشر خاصية من خواص التربة لتحديد هذا المؤشر.

هذه الورقة هى جزء من سلسلة من الورقات التى تستخدم نماذج مطورة لتقنيات مختلفة من تقييم الاراضي باستخدام نظم المعلومات الجغرافية فى مناطق مختلفة من ليبيا. و تم فى هذه الورقة استخدام المؤشر المعدل فى الدراسات سابقة، وتصميم نموذج اكسل في برنامج الميكروسوفت اوفس للقيام بتحليل مؤشر ملائمة التربة ومن ثم دمجها في نظم المعلومات الجغرافية، عن طريق الاعتماد على خريطة تربة رقمية لتخريط درجات الملائمة المختلفة لعدد من المحاصيل الزراعية. و قد بينت النتائج بأن منطقة الدراسة مناسبة لزراعة لمحصول الشعير فقد وصلت الترب الملائمة بدرجة ممتازة للمحصول الى 42 % من ترب المنطقة بينما كانت الترب الغير ملائمة 18 %. اما بالنسبة لمحصول الذرة فأن الترب الملائمة بدرجة ممتازة 29.6 % و تجاوزت الترب الغير ملائمة لمحصول الذرة 24 % من منطقة الدراسة. و بذلك يتيح نظام المعلومات الجغرافية استعراض عدد من السيناريوهات المتمثلة في محاصيل مختلفة لتحديد ملائمة التربة لكل محصول من جهة وكذلك المقارنة بين المحاصيل المختلفة من جهة أخرى. مما يمكن من اختيار انسب المحاصيل طبقا للظروف المحلية واهداف التنمية المنشودة.

الكلمات المفتاحية: الاراضي – المحاصيل – الامن الغذائي – استعمال الاراضي– الاستدامة.