Multicriteria land suitability assessment for growing underutilised crop, bambara groundnut in Peninsular Malaysia

T A S T M Suhairi*, E Jahanshiri and N M M Nizar

Crops For the Future Research Centre (CFFRC), The University Nottingham Malaysia Campus, 43500 Selangor
tengku.syaherah_suhairi@cffresearch.org

Abstract. Bambara groundnut (Vigna subterranea L.) is a high potential indigenous legume with origins from East Africa. Desirable characteristics such as high tolerance to drought, and a more complete nutritional profile nutritional profile has made this legume, a candidate underutilised crop. Underutilised or forgotten crops play an important role in food and nutrition security, agricultural diversification, minimising environmental impacts and mitigating climate variability. Despite having full potential, Malaysia, with fairly established agricultural industry, is not exploiting bambara groundnut or Kacang Poi benefits. Malaysia is predicted to face hotter climates in the future which may affect with potential impact on oil palm and rice production. Therefore, research on alternative or complementary crops such as bambara groundnut is relevant. Major challenge that is limiting the full utilisation of this crop is limited knowledge on where it is suitable to grow based on soil and climate conditions. In this study we delineated suitable areas for the bambara groundnut in Malaysia using available soil, climate, land use/land cover and topography factors. The combination of GIS-based Multi Criteria Decision Analysis (MCDA) with a novel joint soil-climate suitability criteria for bambara groundnut was used in Land Suitability Assessment (LSA) on the areas that are suitable to grow bambara groundnut. Data on soil physical and chemical properties were acquired from ISRIC global soil database. Climate dataset was retrieved from Worldclim which includes monthly temperature and rainfall. The suitability of bambara groundnut was field tested in a highly suitable area (more than 70%) in Semenyih, Malaysia where fresh pod yield of 2.54 MT/ha is reported. The result shows the LSA technique provides an effective assessment tool for land managers and farmers to identify potential areas for potential underutilised crops in agriculture to support Malaysian agriculture.

Keywords: Land suitability assessment, multi-criteria decision analysis, GIS, remote sensing, Bambara groundnut. Underutilised crops, forgotten crops

1. Introduction

Underutilised crop, bambara groundnut is grown widely in Eastern African and mostly grown in the drier parts of sub-Saharan Africa [1]. Bambara groundnut has the agronomic characteristic of high tolerance to drought; ability to yield on lands that are not fertile enough for cultivation of many other crops; and good nutritional characteristics [2]. However, this type of crop is not seen as being valuable to improve food and nutrition security, increase agricultural diversification and minimise environmental degradation [3]. Malaysia has different soil characteristics and climate variables compared to sub-Saharan Africa. Identification of permissible area for growing this underutilised crop...
could be done using suitability analysis and GIS approach. Nonetheless, the suitability of this crop in Malaysia has not been studied much. Therefore, to ensure the optimum production of the bambara groundnut one has to grow the crops where they suit the best. This concludes that the first and foremost requirement is to carry out suitability analysis.

Agricultural sector in Malaysia seems that widely utilised the local agricultural product but many other high potential crops such as bambara groundnut or locally known as Kacang Poi remain underutilised. A crop underutilised due to the lack of consensus definition on what these crop should be referred to as different names such as orphan crop, neglected crop, underutilised crop, forgotten crop, minor crop and etc. Previously, these crop being consider as crop that have not been classifies as major crops, and under research, locally have occupy low levels of utilisation and mainly confined to smallholder farming areas. Historically, such crops have played important roles in ensuring community and household food and nutrition security through providing healthy alternatives when the main crop failed or during periods in between subsequent harvest.

Underutilised crop such as bambara groundnut has a specific criteria to grow in terms of soil chemical and physical properties and climate criteria. Land suitability assessment is the process of determining the best land use option for particular parcel of land [10]. This assessment mainly consider three main data inputs such as: assessment of soil constraints, determination of crop requirement and topography factor [5]. According to [6], suitability is a function of crop requirement and land characteristics. Matching the land characteristics with crop requirements gives the suitability. Thus, suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use. Therefore land suitability analysis has to be carried out in such a way that local needs and conditions are reflected well in the final decisions.

Predictions of future climates show that, Malaysia will face high temperature variable climatic conditions can affect crop production. Therefore, government decisions to find new crops that can grow in Malaysia will play an important role in future of food and nutrition security. This study aimed to determine the suitability for growing bambara groundnut as an exemplar underutilised crop in Malaysia. Factors such as climate and soil chemical and physical suitability were examined to delineate potential suitable areas for growing bambara groundnut in Peninsular Malaysia.

2. Material and methods

2.1 The study area identification
The study area covers the entire Peninsular Malaysia which is located between the latitude of 1°20'6"45'N and longitude of 100°100′30′E. Peninsular Malaysia encompass a area about 131, 311km². Malaysia is characteristically tropical humid with variable topography. This tropical climate characteristics create optimal conditions for the production of fruits and vegetables [7]. Peninsular Malaysia presents favourable conditions for agriculture and it is predominant agricultural region [7].

2.2 Data preparation
This study used the available global datasets that can achieved freely from several databases. This study used georeferenced soil data from SoilGrids database [8] which provides the georeferenced information on soil such as site characteristics, chemical and physical soil properties and soil classification at the global scale. SoilGrids is a product of ISRIC world soil information and is described as a system for automated soil mapping based on global soil profile and environmental covariate data at 250 m with 0.0083 decimal degrees spatial resolution.

Climate dataset were obtained from [4] which provide the average of monthly climate interpolated by the weather stations data with 1 km resolution. The landuse data was obtained from Globcover with 1 km² spatial resolution. Land use requirement is pre-requisite for the proposed landuse. In this study, the consideration is mainly on requirement for growth growing underutilise crop, which is determined by climatic requirements, topography landscape and soil factor. Table 1 below present the description of the data used in this analysis.
Table 1. The list of data used in this study as tabulate below

| No | Data            | Attributes | Resolution | Projection |
|----|-----------------|------------|------------|------------|
| 1  | WorldClim       | Temperature| 1 km       | WGS 84     |
|    |                 | Rainfall   | 1 km       | WGS 84     |
| 2  | Soilgrid        | Soil pH    | 1 km       | WGS 84     |
|    |                 | Depth to the Bedrock | 1 km | WGS 84 |
|    |                 | Soil Texture | 1 km | WGS 84 |
| 3  | Topography      | SRTM       | 30m        | WGS 84     |
| 4  | Globcover Landuse | Landuse/Landcover | 1 km | WGS 84 |

This study using the available global dataset and basically can be achieved freely and it provides the good resolution for this particular region. By having the data from the local data source, with this large extent it is quite costly and time consuming. So, this available global dataset is really useful.

2.3 Land Suitability Assessment Flowchart
We used Land suitability assessment criteria based on an agro-ecological zoning approach that is developed and used by FAO since 1976 [10] It is used to evaluate the suitability of a specific location for producing particular crop to meet the specific crop requirement. The FAO [10] framework for land suitability involves the construction of matching tables or transfer function and subsequent calculation of suitability. Below in Figure 1 shows the assessment flowchart used in this study.

2.4 Data Integration
The environmental data was integrated in order to produce the suitability indices. The mentioned layers are the criteria addressing the suitability of land for the crop cultivation in a particular area. By using the suitability modelling using Ecocrop model the suitability index (0-100%) was obtained [11, 12].

2.5 Crop Agro Climatic and Agro Edaphic Requirement
The crop requirements which are being used to conduct temperature, rainfall and climate suitability ratings are based on data collected from the Ecocrop database. Below, the Table 2 mentioned FAO’s thresholds of temperature, rainfall and other crop parameter.

Table 2. The crop requirements for bambara groundnut retrieved from Ecocrop database [11]

| Crop Parameter           | Optimal | Absolute |
|--------------------------|---------|----------|
| Temperature Requirement  | 19      | 38       |
| Rainfall (Annual)        | 750     | 3000     |
| Latitude                 | -       | 20       |
| Altitude                 | -       | 200      |
| Soil pH                  | 5       | 1400     |
| Light Intensity          | Very bright | Clear skies |
| Soil Depth               | Medium (50-150cm) | Shallow (20-50cm) |
| Soil Texture             | Light   | Heavy,Medium,Light,Organic |
| Soil Fertility           | Low     | Low      |
| Soil Salinity            | Low (< 4 dS/m) | Low (<4 dS/m) |
| Soil Drainage            | Well (dry spells) | Well (dry spells),excessive (dry/moderately dry) |
2.6 Generation of Suitability Index Classification

Suitability index (SI) is defined as the aggregate average land potential of a specific area location to achieve a certain percentage of the maximum attainable yield for a specific crop based on the combined agro-climatic and soil condition [20]. The suitability index used in this study is based on five classes as mentioned below. The suitability index reflects to the suitability composition of particular grid cell of each suitability classes. Based on this assessment, the portion of the grid cell with 80 percent and above represents the high suitable class. Similarly, 60 percent to 80 percent represents suitable class, 40 to 60 percent represents moderately suitable class, then 20 to 40 percent
portion represents unsuitable class and 0 to 20 percent represents the highly unsuitable class. Table 3 below shows the description of each suitability class based on the FAO land suitability classification.

| Code/Order | Class             | Suitability Index (%) | Description                                                                 |
|------------|-------------------|-----------------------|-----------------------------------------------------------------------------|
| S1         | Highly Suitable   | 80-100                | Land without significant limitations. Include the best 20-30% of suitable land as S1. |
| S2         | Suitable          | 60-80                 | Land that is clearly suitable but which has limitations that either reduce productivity. |
| S3         | Moderately Suitable | 40-60               | Land with limitations so severe that benefits are reduced.                     |
| N          | Unsuitable        | 20-40                 | Land that cannot support the land use on a sustained basis.                   |
| N1         | Highly Unsuitable | 0-20                  | Land that cannot support the land use on the productivity                     |

### 2.6.1 Total Climate Suitability

The total climate suitability is based on combination of temperature suitability and rainfall suitability and it follows the Ecocrop model [11] where species niche requirements are examined against the local conditions. For the total climate suitability,

\[
\text{Total Climate Suitability} = \text{TempSUIT} \times \text{RainSUIT} \quad (1)
\]

The temperature suitability described how a crop’s temperature requirement matches the average monthly temperatures at any location [9]. The yearly suitability index was obtained by using the daily monthly maximum and minimum temperature, which further used to compute the temperature suitability. The rainfall suitability is based on the range of precipitation requirement for the crop. Meanwhile, the calculation for the rainfall suitability similar to the temperature except that rainfall does not has the killing amount of precipitation.

### 2.6.2 Total Soil Methodology for determining Suitability indices

The total soil suitability is based on combination of pH soil suitability, soil texture suitability and depth to the bedrock suitability [12]. The reason for averaging soil suitability criteria is that taking the product of all three suitability will render most of soils in Malaysia unsuitable, whereas taking the average is a more moderate measure in determining soil suitability. The equation of the combination as below,

\[
\text{Total Soil Suitability} = \text{AVG}(\text{pHSUIT}, \text{TextSUIT}, \text{DepthSUIT}) \quad (2)
\]

### 2.7 Multi Criteria Decision Analysis (MCDA)

This study was used multi criteria decision analysis (MCDA) technique of land suitability assessment with the use of several parameters such as temperature, climate, soil physical and chemical characteristics, topography and land use to delineate the potential area for growing the bambara groundnut in Peninsular Malaysia. Multi criteria decision analysis (MCDA) involve the integration of several criteria into a single index of evaluation using analytical hierarchy process (AHP) [14, 16]. Each of the criteria maps were integrated into the suitability classes based on the crop requirement.
2.8 Determination of criterion using Analytic Hierarchy Process (AHP)

Determination of criterion weight using AHP involved assigning a value to the criterion based on their importance [13]. This process usually need the expert opinion in order to make the decision in assigning the important on each criteria. Within the comparison matrix, a bigger value implies that one of the criteria is more important that the other for a particular pair of [17]. Using the pairwise comparison matrix, the analytic hierarchy process calculate the weight for individuals criterion by taking eigenvalue corresponding to the highest eigenvector of the completed matrix and the normalizing the sum of the factors to unity [17]. Below Table 4 shows the fundamental scale for pairwise comparison matrix.

| Preference of the criteria          | Intensity of Importance |
|-------------------------------------|-------------------------|
| Two criteria are equally importance | 1                       |
| One criterion is moderately important than the other | 3                       |
| One criterion is strongly important that the other | 5                       |
| One criterion is extremely important that the other | 7                       |
| One criterion is extremely more important that the other | 9                       |
| Intermediate values between adjacent scales values | 2, 4, 6, 8               |

3. Results and Discussions

3.1 Generation of Suitability Map

The Figure 3 (a) shows total climate suitability for growing bambara groundnut in Peninsular Malaysia. The rainfall and temperature suitability data is used to obtain the total climate suitability map. This map shows that most of the area in southern part of Peninsular Malaysia such as in Johor is highly suitable for growing this underutilised crop, Selangor, Negeri Sembilan and others. On the other hand, several parts in north of Peninsular Malaysia seems unsuitable due to the climate condition that having high rainfall.

Meanwhile, the major limitation in land suitability assessment was shown to be physical and chemical characteristic of soil. By considering the soil texture, depth to the bedrock and soil pH the Figure 3 (b) shows the total soil suitability for growing bambara groundnut. Although, most of the area fetch lower suitability in terms of soil suitability due to soil acidity and heavy texture. Bambara can still grow in heavy to sandy loam soils with correct agronomic practices and soil pH can be improved by correct agronomic practices and soil. The Figure 3 (c) shows the altitude suitability for growing this crop in this particular area, the altitude also one of the criteria in this assessment showing that about 40% of the altitude suitability meets the crop requirement which is in between 200-1400m. Thus, after assigning the suitability indices, the pairwise comparison matrix analysis was done using ArcGIS as show in Table 5.

| Criteria                     | Landuse | Elevation Suitability | Total Climate Suitability | Total Soil Suitability | Weight  |
|------------------------------|---------|-----------------------|---------------------------|------------------------|---------|
| Landuse                      | 1       | 0.33                  | 0.14                      | 0.2                    | 0.058822|
| Elevation Suitability        | 3       | 1                     | 0.2                       | 0.33                   | 0.129299|
| Total Climate Suitability    | 7       | 5                     | 1                         | 0.16                   | 0.30108 |
| Total Soil Suitability       | 5       | 3                     | 6                         | 1                      | 0.5108  |

Table 4. The fundamental scale for pairwise comparison matrix [18, 19]

Table 5. The pairwise comparison matrix for multi-criteria decision analysis using ArcGIS
Based on the results, total soil suitability were given high weightage compared to the total climate suitability since these variables were the most limiting factors for land suitability assessment. The weight values of the selected parameters calculated in Analytic Hierarchy Process and designated scores of sub-criterion were used in the Weighted Overlay Analysis to generate the total land suitability for bambara groundnut in Peninsular Malaysia. Table 5 shows the pairwise comparison matrix for multi-criteria decision analysis. Based on the of Food and Agriculture Organization (FAO) classification, suitability was classified into five levels i.e, 1. Highly suitable, 2. Suitable, 3. Moderately suitable, 4. Unsuitable and 5. Highly unsuitable (Table 3). In this study, we combined the suitable and unsuitable orders with their subclasses to provide a more practical approach for classification of land in Malaysia with 5 classes. Due to scarcity of data and lack of access to local data, the classification maps are more suitable for decision makers at the national level this methodology however can be easily extended to higher resolutions with the addition of more parameters with data of better accuracy.

Figure 3 (d) show the elemental suitability’s and the final total suitability, it was determined that 0.7% (842.91 sq km) of the study area be highly suitable for growing bambara groundnut, 24.56% (31 484 sq km) is suitable, 72.36% (95 086.64) is moderately suitable, 2.39% (2 897.08 sq km) is unsuitable and 0.0007% (0.86 sq km) is highly unsuitable. Thus, the present study signifies that the soil physical and chemical properties is the most limiting factor in order to grow the new crop. Despite, this suitability percentage gives a huge potential to grow underutilised crop in Peninsular Malaysia.

3.2 Validation and Verification

Based on the result discussed above, the verification of the suitability was done in a test area located in Semenyih, Selangor. Bambara groundnut’s fresh pod yield of 2.54MT/ha was achieved. Figure 2 shows the established bambara groundnut plot that was planted and harvested in March-July 2017.

![Figure 2. Testing area located in Semenyih](image)

4. Conclusion

Malaysia’s food import almost doubles every 8 years. This high volume has major implications on the country’s food and nutrition security. Bambara groundnut that is an indigenous and resilient crop from Africa has the potential to grow in Malaysia and reduce the dependency in importing plant based protein and starch. This study shows that, bambara groundnut can potentially grow in Peninsular Malaysia. The simple but practical land suitability assessment that was utilised in this article provides the useful decision making approach to helps farmers and decision makers to carried out suitability assessment for a specific crop, specially underutilised crops with little information at any location improve the food production to feed the future.

Acknowledgments

The authors would like to thank Crops for the Future and all colleagues for support and assistance in the research. Thanks for those involved for the great support, valuable suggestion, and recommendation and make all works to be good memory and success.
Figure 3. Generation of suitability map (a) The Total Climate Suitability (b) The Total Soil Suitability (c) The Altitude Suitability (d) The Total Suitability for growing bambara groundnut in Peninsular Malaysia.
References

[1] Azawala, Azam-Ali S.N 2016. Adoption of Bambara groundnut Production and its Effect on Welfare in Northern Ghana. *African Journal of Agriculture Research* 11(7), pp 583-594. doi: 10.5987/AJAR2015.10568

[2] Mayes S., Massawe F.J., Alderson P.J, Robert J.A, Azam-Ali S.N, Herman M. 2012. The Potential for Underutilized Crops to Improve Security of Food Production. *Journal of Experimental Botany*, pp 1075-1079.

[3] Mwale SS, Azam-Ali SN, Massawe FJ. 2007. Growth and Development of Bambara groundnut (Vigna Subterranea) in Response to Soil Moisture 1. Dry matter and Yield. *European Journal Agronomy*, pp 345-353

[4] Fick, S.E. and R.J. Hijmans. 2017. WorldClim 2: New 1-km Spatial Resolution Climate Surfaces for Global Land Areas. *International Journal of Climatology*.

[5] Fick, S.E. and R.J. Hijmans. 2017. WorldClim 2: New 1-km Spatial Resolution Climate Surfaces for Global Land Areas. *International Journal of Climatology*.

[6] Getachew T.Ayehu, Solomon A.Besufekad. 2015. Land Suitability Analysis for Rice Production: A GIS Based Multi-Criteria Decision Approach. *American Journal of Geographic Information System*, pp 95-104

[7] Abul Quasem Al-Amin, Walter Leaf Filho. 2011. Assessing the Impact of Climate Change in the Malaysian Agriculture Sector and its Influences in Investment Decision. *Middle-East Journal of Scientific Research*, pp 225-234.

[8] Hengl, T. Mendes de Jesus,J., Heuvelink, G.B.M, Ruiperez Gonzalez, M., Kilibarda, M. et al. 2017. SoilGrids250:Global Gridded Soil Information Based on Machine Learning. PLoS ONE 12 (2).

[9] C.Roger Bowen and Steven E. Hollinger. 2005. Model to Determine Suitability of a Region for a Large Number of Crop. Urbana,Illinois: Illinois Council fo agricultural and Food Research

[10] Food and Agriculture Organization. 1976. A Framework for Land Evaluation, Soil Buletin 32. Rome: Food and Agriculture Organization of United Nations.

[11] Ramirez-Villegas. J. A. and Laderach,P. 2013. Empirical Approaches for Assessing Impacts of Climate Change on Agriculture: The Ecocrop model and A Case Study with Grain Sorghum. *Agricultural and Forest Meteorology*, pp 67-78.

[12] Jahanshiri,E. 2017. Combined Soil-Climate Suitability for Crop Suitability. Pedomentrics. Wageningen, The Netherlands

[13] A.O. Olaniyi, A.J, Ajiboye,A.M Abdullah,M.F Ramli and A.M Sood. 2015. Agricultural Land Use Suitability Assessment in Malaysia. *Bulgarian Journal of Agricultural Science*, pp 560-572.

[14] Maleczewski J. 1999. GIS and Multi-Criteria Decision Analysis. London: Wiley.

[15] Food and Agriculture Organization. (2012). Assessing Suitable Land: The Methodological Framework and its Implementation. Rome: Food and Agriculture Organization of United Nations.

[16] Maleczewski J. 2006. GIS-Based based Multi-Criteria Decision Analysis: A Survey of the Literature. *International Journal Geographical Information Science*, pp 703-726.

[17] Saaty T.L. and L.G Vargas, 1991. Prediction, Projection and Forecasting, Dordrecht. The Netherlands: Kluwer Academic Publisher.

[18] Saaty T. L. 1977. A Scaling Method for priorities in hierarchical structures. *J Math Psychol* 15, pp 234-281.

[19] Saaty T.L. 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. New York: Mc Graw Hill International.

[20] Food and Agriculture Organization of United Nations. 2012. Natural Resources Assessment for Crop and Land Suitability: An Application for Selected Bioenergy Crops in Southern Africa Region. Rome: Food and Agriculture Organization of United Nations.