Land Capability for Agriculture, Hermel District, Lebanon

Sandra Abou-Najemab, Guillermo Palacios-Rodríguezc, Talal Darwishb, Ghaleb Faourb, Salim Kattard, Inmaculada Clavero Rumbao and Rafael Mª Navarro-Cerrilloa

aFaculty of Agricultural and Forestry Engineering, Forestry Engineering Department, University of Córdoba, Spain; bNational Center for Remote Sensing, National Council for Scientific Research (CNRS), GIS and Remote Sensing Department, Lebanon; cCenter for Applied Research in Agroforestry Development (IDAF), Research and Development Department, Spain; dFaculty of Agricultural Sciences, Department of Environment and Natural Resources, Lebanese University, Lebanon

ABSTRACT

For the purpose of mapping land capability by United States Department of Agriculture (USDA) criteria, this paper presents a validated model to map land capability at a scale of 1:20,000 using a digital elevation model and the available soil information for Hermel District (525.6 km²) in Lebanon. The model was validated through fieldwork and it indicates a good overall accuracy of 89% and the significance of the model for mapping land capability at a district level. The study shows that 11.5 km² (2.2%), 284.6 km² (54.2%), 66.8 km² (12.7%), 147.9 km² (28.1%) and 14.9 km² (2.8%) of the region were categorized in I, II, III, IV, and V land classes respectively. The comparison between the zoning map already produced for Hermel city and the land capability map demonstrates that the land use patterns need to be modified according to identified land capability classes to sustain the remaining productive lands for future generations.

1. Introduction

Hermel District is the main region of the Orontes basin in Lebanon. Agrarian changes in the region increased tensions on land uses and overexploitation of irrigation water. Partial disengagement of the State in Hermel provoked adverse impacts on land and water resources. The uncontrolled use of these resources caused especially water erosion of the soil and the overexploitation of groundwater (Hamade, 2012). As of 2014, Lebanon was facing a summer drought after a record dry winter coupled by a massive influx of Syrian refugees and long-standing water management problems. This drought lowered the groundwater level and decreased the flow of the springs. A direct consequence is the threat to the agricultural sector in this country (Faour, Mhawej, & Abou Najem, 2015). With the increasing of human pressure on limited land resources, the analysis of land system management and soil degradation gains exclusive interest. One of the most important land evaluation attempts in Lebanon was during 1997–2001, when soil mapping based on modern techniques and large fieldwork was undertaken. It allowed the excavation of more than 400 profiles, which were described according to the FAO guide (1990) and sampled horizon wise (Darwish, Jooma, Awad, Abou Daher, & Msann, 2005). Samples were analysed for their main physical and chemical characteristics. Soil types were classified following the Soil Survey Staff (1996), FAO-UNESCO revised Legend (1997) and World Reference Base for Soil Resources (1998) and a new soil map of Lebanon was produced (Darwish et al., 2006). The soil map offers a remarkable potential to constitute a tool to solve agriculture problems, in practice; however, it remains underutilized because of its complex scientific nature (Rushemuka, Bock, & Mowo, 2014). Soil scientists have realized the challenges of using these maps to work in a trans-disciplinary fashion (Bui, 2004; Wielmaker, De Bruin, Epema, & Veldkamp, 2001). The information of the soil map must be explained in an easy way that has meaning to the land-owners, decision-makers and land-use managers. Land capability classification acts as an important tool for land’s better use. Classifying lands based on their capability at region level would help decision-makers in the identification of different soil types in accordance with its capability for sustainable soil fertility management. Land capability is the ability to accept a type and intensity of land use permanently, or for a specified period under a certain management without long-term degradation (Rees, 1995). Capability classes are groups that have the same relative degree of hazard or limitation to agricultural and non-agricultural uses. United State Department of Agriculture guidelines (USDA, 1973) have been applied to determine land capability with eight classes designated with Roman number I–VIII (Ayalew, 2015). The first four classes are suitable for...
agriculture in which the limitation on their use and necessity of conservation measures requires a careful management increase from I to IV (Sys, Van Ranst, & Debaveye, 1991), and the remaining classes are unsuitable for cultivation (Atalay, 2016). In 2004, a small-scale survey produced the land capability map of Lebanon by combining several layers related to the geomorphology and soil characteristics at a 1:200,000 scale (Darwish et al., 2005). At such scale, land capability classification can be used for providing a land quality inventory for Lebanon’s agriculture land resource and identifying areas of agricultural interest mainly but not to plan urban and rural development, to locate the irrigation schemes and to plan transport, industrial development and telecommunication at a district level. Figure 1 shows the zoning map produced for Hermel city provided by Planning and Development Agency (PDA). The objective of this map was to put land to the use for which it is best suited but it was done without taking into consideration the land capability of the city. This paper presents a methodological approach and application of land capability assessment method which is designed for use at a small catchment level, using the commonly available soil data and the Digital Elevation Model (DEM). A description of the study area is presented first, followed by the methodology of land capability classification capability at a scale of 1:20,000.

Results are presented after to spatially classify lands based on their capability and to assess the degree of conformance of the land use designations of specific parcels proposed by the zoning map already established for Hermel city to the output land capability map.

2. Methods

2.1. Description of the study area

Hermel District is the main area of the Orontes Basin in Lebanon. Spatial extent of Orontes Basin is ranging from latitude 34° 1’ 8” to 34° 2’ 9” North and 36° 7’ 44” to 37° 7’ 53” East. Hermel District covers a total area of 538 km², equivalent to 5% of the total area of Lebanon. It is located at the extreme Northern Eastern part of Lebanon (Figure 2). The study area is characterized by an altitude that varies between 500 and 3000 m. It lies in the semi-arid zone and has extreme summer with the temperature reaching 40°C. Average annual rainfall varies between 300 and 1300 mm, 80% of it is during the rainy season. January is the coldest month and August is the hottest month. The relative humidity varies between 62% and 70% during the wet season and between 44% and 48% during the rest of the year. The annual rate of evaporation is 1750 mm (Fonbonne, 2000).

Figure 1. Zoning map of Hermel city.
Notes: PDA provided us with the zoning map of Hermel city. The objective of this map was to put land to the use for which it is best suited.
2.2. Parameters considered for land capability mapping

The slope is the first parameter used in the equation of Land capability classification, it is a physical parameter computed from the DEM retrieved from https://earthexplorer.usgs.gov/ in ArcGIS environment. The four other parameters are measured soil parameters: soil depth, clay content, organic matter content (OM) and CaCO₃, they were generated from the unified soil map of Lebanon 1/50,000 (Darwish et al., 2006).

2.2.1. Slope

Slope is undoubtedly one of the most important factors to be considered in a capability classification. Slope gradient as a topography factor plays an important role on impacting soil erosion intensity (Zhang et al., 2015). Hermel District is characterized by the abundance of level and rolling lands on the eastern slopes and sloping and steep lands with slope gradient over 30% in the central part and on the west. In this study, slope is measured in percentage and recorded as one of the five slope groups categorized as follows:

- <5%: Level lands,
- 5–8%: Rolling lands,
- 8–15%: Slopping lands,
- 15–30%: Steep lands,
- >30%: Very steep lands.

2.2.2. Soil depth

Soil depth is probably one of the most important factors in classifying land capability. Effective depth includes the total depth of the soil profile favourable for root development (Rees, 1995). Capability increases with the depth to solid bedrock. The area of study is characterized by the dominance of moderately deep and shallow soils which can reduce the area of the green cover as old and relict junipers forest is extremely rare and dispersed. Based on prevailing soil depth, this factor was classified into four classes with high positive effect on land capability classes (LCC) for soils having depth >75 cm, moderate effect for soils having a depth of 50–75 cm and low effect for soils having depth 25–50 cm, very low effect for soils having depth 10–25 cm. Soils having a depth less than 10 cm were considered as non-arable.

2.2.3. Clay content

The clay content may be used to judge the suitability and capability of the soil because it affects the soil...
water content. Soils with as little as 20% clay size particles behave like a sticky clayey soil. Soils with high clay content have good water and nutrient holding capacity (Whiting, Card, Wilson, Moravec, & Reeder, 2015). The clay content of >30% and <40% was attributed to the best effect on LCC due to clay positive impact on soil structure and cation exchange capacity. The moderate effect was credited to soils having clay content between 20% and 30%, low effect for soils having clay content greater than 40%. Capability of lands having clay content less than 20% is considered very low. A large part of the study area is characterized by clay and loamy soils. Soils with prevalence of silt and or sand, located to the west of the area of study, constitute a significant part of the soil types of Hermel District.

2.2.4. Organic matter content

The inherent capacity of soil to retain water mostly depends on specific soil parameters, such as soil texture, soil structure, and soil organic matter (SOM) content (Mudgal et al., 2014). The organic content of soil greatly influences the plant, animal and microorganism populations and decomposing organic material provides many necessary nutrients to soil inhabitants (Whiting et al., 2015). The slopping mountainous lands of the area of study are mainly characterized by relatively high organic matter content due to the effect of the relict forest and appropriate climatic conditions favouring natural vegetation and input of plant residues to the soil. The area of the level plains subject to cultivation and plowing showed lower level of organic matter content.

2.2.5. CaCO3 content

CaCO3 content has a significant effect on dry matter and grain yield (Patil & Patil, 1981). The mountainous soils are characterized by low CaCO3 content which matches the prevailing climatic conditions and leaching of CaCO3 from the soil. Therefore, the soils of the low lands are characterized by enrichment in CaCO3 which favours the formation of petrocalcic layer and affects the productivity of calcifuges crops.

2.3. Data resources

LCC were defined using information available from the unified soil map of Lebanon at a scale of 1:50,000 (soil depth, clay content, organic matter content and CaCO3). This information in conjunction with slopes data taken from the 30 m resolution DEM were used to define land capability.

2.4. LCC model, fieldwork, model validation and results

2.4.1. LCC model

Table 1 displays the five LCC and the five related parameters on which the land capability model was based. The values of parameters (slope, soil depth, clay content, organic matter content, CaCO3) were generated from the unified soil map of Lebanon (1/50,000). The choice of parameters was based on previous studies on land capability classification (Ayalew, 2015; Mary Silpa & Nowshaja, 2016; Panhalkar, 2011).

The most common factors used in previous studies were slope and soil depth. They were given the highest weights in this study: 30% was allocated to slope gradient and 25% was allocated to soil depth. Organic matter, clay content and CaCO3 were not common in previous studies; they are supposed to have less influence on land capability, they were equally assessed and given a weight of 15%. Each factor was assigned a score ranging from 1 (best land capability) to 5 (the poorest land capability). Finally, all these parameters are integrated by weighted summation to calculate land capability classes based on the equation below. Figure 3 summarizes the flow chart of the methodology used.

\[
LCC = \text{Slope} \times 0.3 + \text{Soil depth} \times 0.25 + \text{Clay content} \times 0.15 + \text{CaCO3} \times 0.15 + \text{OM} \times 0.15. \tag{1}
\]

2.4.2. Fieldwork

A total of 106 sample field points were used to validate the model (Figure 2). Survey points are irregularly

| Attribute          | Land Capability Class |
|--------------------|-----------------------|
|                     | I High               |
|                     | II Moderate          |
|                     | III Low              |
|                     | IV Very Low          |
|                     | V Non-Arable         |
| Category            |                      |
| Slope, %            | <5                   |
| Soil depth, cm      | >75                  |
| Clay, %             | 30–40                |
| O.M. %              | >5                   |
| Active CaCO3, %     | <3                   |

Notes: Table 1 displays the five land capability classes (LCC) and the five related parameters on which the land capability model was based: slope gradient, soil depth, clay content, organic matter content and CaCO3 level. Each factor was reclassified based on their influence on land capability. A given weight for each classified factor was allocated depending on its importance for the assessment of potential soil productivity. A total of 30% was allocated to slope, 25% was allocated to soil depth and the rest three factors were equally assessed 15%.
located according to the survey team’s judgment to enable the delineation of soil boundaries and checking of model output. Coordinates were registered for all field points with a real-time differential global positioning system (GNSS/GPS Systems, Leica). The error accepted for GPS measurements was limited to an EPE (Estimated Position Error) <1 m. Capability class of each point was recorded to compare it with the LCC (land capability classification) generated by the model.

### 3. Results

#### 3.1. Model validation

The validation of the land capability map is crucial for this study. Detailed observations were made during field survey to classify the 106 field points into the 5 capability classes and the results were compared with the land capability map. An accuracy analysis was then conducted and an error matrix was established between the modelling results and the field observations. It indicates a good overall accuracy of 89% (95/106). The user’s accuracy, the percentage of sites belonging to a model class correctly corresponds to field data is 82–100%, and the producer’s accuracy, the percentage of sites belonging to field class correctly classified by the model is 82–93% (Table 2).

#### 3.2. Land capability for agriculture map of Hermel District

As the main result (Main Map), this work presents the Land Capability for Agriculture Map of Hermel District (Figure 4), based on the methodology described. The map (Figure 4) shows five categories of lands:

1. **Class I** represents lands with very minor or no physical limitations to use. These arable lands are spread in the North Eastern part of Hermel District and small patches in the Central South part. They represent 2.2% of the district total area. These soils are characterized by a suitable access for roots to moisture and a gentle slope. A wide range of crops can be grown and yields are good.

2. **Class II** represents soils with minor limitations that reduce the choice of crops or require moderate conservation practices, or both. These soils are spread in the North Eastern part of Hermel District and small patches in the Central South part. They represent 2.2% of the district total area. These soils are characterized by a suitable access for roots to moisture and a gentle slope. A wide range of crops can be grown and yields are good.

### Table 2. Validation of land capability model.

| Model predictions | Ed(%) | Pu(%) | Total | 5 | 4 | 3 | 2 | 1 | LCC |
|--------------------|-------|-------|-------|---|---|---|---|---|-----|
| 8%                 | 92%   | 14    | 0     | 0 | 0 | 1 | 13|    | 1   |
| 8%                 | 92%   | 26    | 0     | 0 | 1 | 24| 1 |    | 2   |
| 7%                 | 93%   | 29    | 0     | 0 | 27| 2 | 0 |    | 3   |
| 18%                | 82%   | 17    | 0     | 14| 2 | 1 | 0 |    | 4   |
| 15%                | 85%   | 20    | 17    | 3 | 0 | 0 | 0 |    | 5   |
|                    |       | 106   | 17    | 17| 30| 28| 14|    | Total |
| Pu=89%             |       | 100%  | 82%   | 90%|85%|92%|  |    | Pu(%) |
|                    |       | 0%    | 18%   | 10%|15%|8% |  |    | Ee(%) |

Notes: Ed = error deficit (omission); Pu = user’s precision; Ec = excess error (commission); Pp = producer’s precision; Ed = deficit error (omission); Pt = total precision. Table 2 presents the error matrix done between the modelling classification and the field observations.
spread mainly in the East, central South and North West parts of Hermel District. The moderate capability class is large and constitutes 54.2% of the district area. Limitations may include moderate slopes, slight erosion or slightly unfavourable soil texture. A wide range of crops can be grown and winter harvested crops may not be ideal because of harvesting difficulties.

(3) Class III includes lands having limitations that require moderately intensive management practices or moderately restrict the range of crops, or both. These lands spread in the North and South central parts of Hermel District constituting 12.7% of the total area. The limitations affect the range of crops which are restricted mainly to grass, cereal and forage crops. Limitations are more difficult to correct and they include strongly sloping ground, imperfect drainage or severe climate. If terraced, they become of better productivity and thus might be planted with fruit trees.

(4) Class IV refers to land with severe limitations that restrict the choice of crops and/or require very careful management practices. The area of very low productivity lands is the largest. It constitutes 28.1% of the casa total area. This class is widespread in the central parts and West boundaries of the district. Limitations are due to very stony soils, steep gradients and presence of petrocalcic layer: friable secondary calcium carbonate rock of 30–50 cm of thickness, found in the level lands of the eastern part of Hermel District. If these layers are removed by rippers and soils are ploughed, the land becomes class II or III as deep soil layer is found beneath the removed secondary rocks. But land reclamation requires large investment cost.

(5) Class V groups all the non-arable lands or lands with severe limitations that restrict their use to pasture, grazing, forestry and recreation. The area of non-arable lands is estimated at 14.9 km². It constitutes 2.8% of the total area. These soils are spread in the West part of the district and form small patches in the North East and West boundaries of the casa. Limitations result from steep slopes, severe risk of erosion and shallow soils. The land has a wide range of capability for grazing, forestry and recreation.

4. Discussion

The slopes on the mountainous areas form class V lands, in general. These areas have high percentage of

Figure 4. Land capability for agriculture map of Hermel District.
Notes: Figure 4 presents the final land capability classification map. The study shows that 11.5 km² (2.2%), 284.6 km² (54.2%), 66.8 km² (12.7%), 147.9 km² (28.1%) and 14.9 km² (2.8%) of the region were categorized in I (high land capability), II (moderate land capability), III (low land capability), IV (very low land capability), and V (non-arable) land classes respectively.
stoniness and steep slopes which make them unsuitable for agriculture. Only drought-resistant trees, like Juniper, are able to grow in such conditions. Generally, class IV occurs along the foothills of the mountains and the level lands of the Eastern part. This class shows the development of petrocalcic horizon which is a thick deposit that can be removed by rippers. These layers are the result of an extreme evapotranspiration reaching 1500 mm per year and restricted amount of rainfall (<300 mm). Northeastern and central South parts of the district are mainly the lands belonging to land capability classes I, II and III.

The comparison between land capability classification and the zoning map of Hermel city are presented in Table 3 to assess the degree of conformance of the lands use designations of specific parcels proposed by the zoning map to the land capability map obtained in this work.

The results of this analysis show that the zoning map made for Hermel city did not take into consideration the soil capability of lands. Less than 1% of the classified agricultural lands are on high capability class and most of the habitations were classified within the high and moderate land capability classes. It was found that the conventional land evaluation methods suffer from limitation of spatial analysis (AbdelRahman, Natarajan, & Hedge, 2016) this implies that the poor agricultural productivity does not come from poor soil fertility but it is a result of the weak control of the land’s use. Since most of the land in Hermel city is suitable for agriculture, therefore it is preferable to relocate industrial and residential structures to non-arable and very low regions outside the city and give support to the agricultural sector to be an investment destination for the upcoming years.

This analysis shows that 56.3% of the district area can be termed as lands suitable for agriculture; they have slight limitations restricting their use or reducing the choice of plants. They require few management practices to grow crops. At a smaller scale (1:200,000), the land capability map produced for Lebanon in 2005 showed that the whole Hermel District is characterized by the presence of shallow soils which represent a serious problem for agriculture (Darwish et al., 2005). Based on the land classification of 2005, Hermel District has been classified into class III that represents soils having severe limitations and requiring special conservation practices. Although the land capability map of 2005 and the one published in this study used basically the same methodology, the results were different. The small scale used in 2005 classification does not show well the variability of soil characteristics as the large scale of the current study does. It should be noted that the validity of the analysis is related to the scale of the input maps. For more detail planning, more detailed input maps are required.

The model shows a good overall accuracy of 89%, this indicates that the values of weights were well chosen with slope having the highest role in determining land capability. This may be caused by the landscape of the study region that is characterized by the presence of slopping and steep lands with slope gradient over 30% especially in the Central part and on the West. Although the results were considered to be valid, the application of this model in other regions with different characteristics in term of slope and soil composition is suggested to verify the validity of this model in all types of topography. It is necessary additional factors containing detailed climatic, geomorphic and topographic parameters that have impact on land capability and environmental sustainability. This map will provide a tool for the urban master plans that are under preparation because a big part of Hermel District is among the regions not yet zoned in Lebanon. The model, thus developed demonstrates its significance for the land capability classification and the application of this model over all Lebanon and other countries is suggested to validate the usefulness of this method in

### Table 3. Percentage of each capability class from each zoning class.

| Zoning class                  | I  | II  | III | IV  | V   | Non-arable | Total area (km²) |
|------------------------------|----|-----|-----|-----|-----|-----------|-----------------|
| Agricultural area            | 0.705204 | 98.6021 | 0.632992 | 0 | 0 | 9.480364  |
| Area extension first         | 0 | 99.41552 | 0.584476 | 0 | 0 | 5.786021  |
| Area extension second        | 0 | 100 | 0 | 0 | 0 | 0.853027  |
| Environmental protected area| 1.652527 | 74.96066 | 3.30931 | 17.59763 | 0 | 11.25721 |
| First habitation             | 0 | 100 | 0 | 0 | 0 | 1.596621  |
| Future extension             | 0 | 82.03777 | 16.06914 | 0.455867 | 0 | 3.816736  |
| Habitation and business      | 0 | 100 | 0 | 0 | 0 | 0.498936  |
| Industrial area              | 0 | 100 | 0 | 0 | 0 | 0.359202  |
| Natural protected areas      | 0 | 83.30109 | 15.84012 | 0.548753 | 0 | 5.716644  |
| Private habitations/Villas   | 0.145053 | 99.85495 | 0 | 0 | 0 | 0.238302  |
| Protected Assi river         | 65.63393 | 21.19023 | 0 | 0.001698 | 0 | 0.786959  |
| Public institutions          | 0 | 99.00399 | 0.996006 | 0 | 0 | 0.238302  |
| Second habitation            | 0 | 100 | 0 | 0 | 0 | 2.281281  |
| Third habitation             | 0 | 100 | 0 | 0 | 0 | 2.233516  |
| Touristic area               | 9.378931 | 85.71911 | 0.511625 | 3.143368 | 0 | 4.021023  |
| Total                        | 2.327052 | 88.19887 | 4.075062 | 4.374958 | 0 | 49.28431  |

Notes: Table 3 shows the different zoning classes in Hermel city, the area of each class and the percentage of each capability class from each zoning class.
different climatic regions to discover other parameters that may be later incorporated to the model described in this paper. Finally, the results demonstrate that the land use pattern need to be oriented according to land capability classes to increase the efficient use of lands for agriculture. The results obtained indicate that in some areas the use of the land is not the most appropriate (for example, areas of high agricultural productivity are used for other purposes such as urban development, while areas with little capacity to support crops are used for agriculture, offering very poor production). The land capability map for agriculture could give a general orientation about the use of the soil. All the high-class lands could be used for agriculture because they have no limitations. All the non-arable class lands can’t be used for agriculture because the cost needed to modify the soil is so high. To suggest land use activities the study of land capability is not enough, this study should be followed by land suitability study and other detailed studies to suggest correct land use for each parcel of this region. Such kind of analysis enables decision-makers to develop crop managements able to increase the land productivity (Abdel-Rahman et al., 2016). The obtained map offers more detail on the land capability for agriculture in the study area, so it can be used as a planning tool by public management bodies to contribute to more efficient land planning.

5. Conclusions

This work shows that Geographical Information System provides a tool to overlay multi-layer of data and to produce the land capability map. This map will certainly help decision-makers to control urban expansion and follow the implementation of rules for the construction on relevant land capability classes. They have now the ability to propose fine tuning of the land use planning developed centrally based on small-scale maps. Controlling land use change, land use options and urban expansion can help preventing land degradation by chaotic urban sprawl, support suitable land use, and raise awareness to hasten local governance for the protection and sustainable use of natural resources in the area. For its effective use, it is needed to increase policy-maker’s awareness about the capability of soils and provide land use planners with information on the land’s best use. A strong communication between soil experts and decision-makers is likely to increase sustainable use of lands and to help in environmental protection if earlier interventions are made.

Software

Arcmap™ (ESRI, v.10.3) was used to generate the soil parameters shapefiles and to compute the slope from the DEM (digital elevation model), including the calculation of the land capability classes and the production of the final LCC map. The 30 m spatial resolution DEM retrieved from open source (https://earthexplorer.usgs.gov/) was used to generate slope by using ‘Spatial Analyst Tool Surface Slope’ in Arcmap™ (ESRI, v.10.3) environment. The slope and other soil parameters (soil depth, OM, clay content, CaCO3) were reclassified and grouped into five classes (from 1 to 5) based on their influence on land capability. Soil parameters are integrated by weighted summation using ‘Field calculator tool’ to calculate land capability classes based on Equation (1) in ArcGIS environment. LCC Model validation and statistical analysis were performed using SPSS.

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ORCID

Guillermo Palacios-Rodriguez http://orcid.org/0000-0001-8786-0211

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