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Comparing Two Methods of Soil Data Interpretation to Improve the Reliability of Land Suitability Evaluation

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ABSTRACT

Sustainable management of limited land and water resources is urgently needed to meet the increasing demand for food and to protect the environment. Land suitability analysis is a prerequisite in assessing and proposing sustainable land use alternatives for an area. Soil data are usually available at different levels of detail and stored in various forms, usually soil maps and/or soil observations. Soil data interpretation methods control the reliability of land suitability evaluation results. This has a serious effect on the reliability of the suitability maps, the subsequent land use decisions, and environmental modeling. This study examines the reliability of land suitability mapping using different methods of soil data interpretation – the average of land characteristics for field observations within soil map units (point-in-polygon) and spatial interpolation using field observations only (proximity to points). The degree of agreement between the two methods depends on the type of land utilization – rainfed barley (86%), open range (85%), improved range (75%), drip irrigated vegetables (69%), and drip irrigated trees (59%). This results from the difference in the limiting land characteristic that determines the suitability of each land utilization type and the pattern of spatial variation of each land characteristic in the field. Suitability maps for adaptable (indigenous) crops (such as barley and range crops), which require minimum farming inputs, are generally more accurate because they tolerate a wider range of variability. The interpolation method was more efficient in detecting the spatial distribution and extreme values of limiting land characteristics, resulting in more accurate suitability maps. Therefore, when detailed soil maps are not available, field observations could be used to derive suitability maps using an exact interpolation method.

Keywords: Indigenous crops, Interpolation, Land characteristics, Spatial distribution, Thiessen polygons.

INTRODUCTION

Limited natural resources in the arid regions necessitate the improvement of agricultural productivity to meet the increasing demand for food. To achieve this, appropriate and sustainable land use schemes are required. The first step in the development of land use schemes is the evaluation of biophysical land resources. Land evaluation is defined as "the process of assessment of land performance when used for specific purposes" (FAO, 1985), or as "all methods to explain or predict the use potential of land" (Van Diepen *et al.,* 1991). Once this potential is determined, land use planning can proceed on a rational basis, at least with respect to what the land resource can offer (FAO, 1993; Rossiter, 1996; Hosseini *et al.,* 2009).

The Food and Agriculture Organization of the United Nations (FAO) indicated that there is an urgent need to optimize land use in the most practicable and logical ways to continue sustainable production while conserving fragile ecosystems (FAO, 1993). Land suitability analysis is a prerequisite for achieving the optimum utilization of available land resources for sustainable agricultural

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production (Nisar_Ahamed *et al.,* 2000). In this context, land suitability evaluation can constitute a preliminary tool towards better land management and mitigate land degradation (D'Angelo *et al.,* 2000; Mashizi *et al.,* 2009).

The FAO approach to land suitability evaluation classifies land according to a range – from highly suitable to not suitable – based on climate, terrain, soil properties and other land use related characteristics (FAO, 1976). This procedure starts by identifying relevant land use types. The land use requirements are then matched with defined land conditions. The land conditions are described as dynamic regimes or land qualities, which are estimated from measured or estimated attributes, known as land characteristics (Melitz, 1986).

The quality of land suitability assessment, and hence the reliability of land use decisions, depend largely on the quality of the soil information used to derive them (FAO, 1976; Ghaffari *et al.,* 2000; Mermut and Eswaran, 2001; Bogaert and D'Or, 2002; Salehi *et al.,* 2003; Mahmoodi *et al.,* 2007). Furthermore, the method of processing the soil information might improve or worsen the quality of the derived suitability maps. With limited detailed coverage of soil information, it is necessary to optimize the use of available soil data to produce accurate suitability maps. The consequences of inaccurate suitability mapping might be irreversible, especially in land resource planning and environmental modeling. Data processing and interpretation using geographic information systems (GIS) provides new opportunities to improve the reliability of suitability mapping using the available soil data (Mermut and Eswaran, 2001; Naderi Khorasgani and De Dapper, 2009).

Two approaches are frequently used to process soil information. One approach is to calculate the average value of the soil characteristics using soil observations within each soil map unit – a typical point-in-polygon analysis (Bello-Pineda *et al.,* 2006). In this case, the quality of the suitability map varies according to the level of soil mapping, which determines the purity of the soil map units. This approach was utilized for land suitability evaluations in Jordan in some projects and researches (MoA, 1995; Mazahreh, 1998; Hatten and Taimeh, 2001). However, suitability maps derived by calculating the average of soil observations within soil map units, only partially reflected the situation on the ground (Ziadat, 2000), because it does not fully account for the within map unit variability. A study by Drohan et al. (2003) indicated that the purity of map units is less than 50%, which may lead to erroneous conclusions when these maps are used to derive suitability maps (Riezebos, 1989). Conventional Boolean models to assess land suitability ignore the continuous nature of the soil and landscape, which might lead to inaccurate classifications. Therefore, researchers suggested applying the fuzzy set theory for land suitability evaluation (Keshavarzi *et al.,* 2010; Elaalem *et al.,* 2011). Furthermore, error propagation as a result of using the derived suitability maps in land resource management and environmental modeling might lead to devastating consequences.

Many land characteristics vary over a short distance within any map unit (Burrough, 1992). The simplification of this variability into one representative value for the map unit may reduce the accuracy of the suitability map and raise questions about its reliability (Riezebos, 1989). Detailed surveys showed greater variability in soil types within a 50 hectare study site than hypothesized by the soil map (Shahid *et al.,* 2004). This raises the question of how the reliability of the land evaluation can be improved, given the variability of land characteristics within soil map units (Riezebos, 1989; Burrough, 1992; Oberthur *et al.,* 1996). New approaches that can be employed to cope with these challenges include fuzzy classification methods, multivariate regression methods, spatial interpolation methods, artificial neural networks (ANNs), data envelopment analysis (DEA), and decision trees (Sarmadian and Taghizadeh Mehrjardi, 2009; Namdar-Khojasteh *et al.,* 2010a, b; Parvizi *et al.,* 2010; Zangeneh *et al.,* 2011; Heidari *et al.,* 2012)

An alternative approach, to cope with the spatial variability, is systematic, high-density sampling and the subsequent use of spatial interpolation techniques to produce maps that cover the whole area from which suitability maps are derived (Burrough and McDonnell, 1998; Bogaert and D'Or, 2002; Payton *et al.,* 2003). However, this approach is expensive because of the large number of observations required to obtain meaningful results (Riezebos, 1989; Van Kuilenburg *et al.,* 1982; Ziadat, 2000).

The objective of this study is to compare the reliability of land suitability mapping for different approaches to soil data interpretation. One approach is a mathematical calculation of land characteristics using field observations and soil map units and the other is a spatial interpolation between field observations only. The ultimate goal is the improvement of land evaluation results to support sustainable land use decisions.

MATERIALS AND METHODS

Study Area

The study area is located in the north of Jordan, between latitudes 32° 22´ and 32° 45´ North and longitudes 36° 22´ and 36° 45´ East, and covers an area of 148 km^2 (Figure 1). Most of the area is formed from old colluvial material on a basalt plateau and dominated by Calcids with inclusions of Cambids (MoA 1995; USDA, 2003). Generally, it is a very gently undulating lava plain with slopes in the range 1-4% and altitudes in the range of 650-750 m above sea level. Most of the soils have a transitional xeric-aridic moisture regime and thermic temperature regime. The mean annual precipitation for the study area is about 175 mm. The average annual temperature is 16.5°C, while the annual mean minimum temperature is 9.2°C and the maximum 23.9°C. The mean relative humidity is 56% (Department of Meteorology, 1995).

Selection of Land Suitability Criteria

Land suitability evaluation was performed according to the FAO framework for land evaluation (FAO, 1976). The first step was to select the land utilization types (LUTs), which takes into account previous studies in this area, in particular, and in Jordan in general (MoA, 1995; Mazahreh, 1998; Hatten and Taimeh, 2001; Ziadat, 2007). An important assumption is that the low rainfall within the study area is not enough to support rainfed cultivation. The general prevailing land use pattern within the study area was also considered in the selection process. The following potential LUTs were selected and proposed for implementation in the area: open range, improved range by using minor pits for water harvesting, rainfed barley for livestock grazing, drip irrigated vegetables, and drip irrigated trees.

The selection of land qualities and the rating of the criteria for land suitability classification were derived and modified from previous projects and research (Tables 1 and 2) (MoA, 1995; Mazahreh, 1998; Hatten and Taimeh, 2001). A major consideration in the selection of land qualities is their expected effect on the

Figure 1. Location of the study area (Al-Mafraq) within Jordan.

Table 1. Land use limitations, land qualities and land characteristics.

Limitation	Land Qualities	Land Characteristic	Unit
Climate	Moisture regime	Precipitation	mm
	Temperature regime	Winter growth potential [a]	Degree-days
Soil	Rooting condition	Available water holding capacity	mm
		Soil depth	cm
Erosion	Erosion hazard	Rill or Gully	Class
		Sheet/ Wind/ Undifferentiated	Class
Topography	Topography	Slope	%
Rock outcrop/Stones	Conditions for germination	Rock outcrop	%
		Stone at surface	%
		Stone content in surface horizon	%

[a] Winter Growth Potential (WGPT): summation of degrees greater than 8 ºC during the coldest months.

Table 2. Land use requirements for different land utilization types.

Land Characteristic	Open range				Improved range				Rainfed barley				Irrigated vegetables				Irrigated Trees			
	S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS	S1	S2	S3	NS
Precipitation (mm)	100	75	50	<50	200	150	100	<100	250	200	150	<150	NA	NA	NA	NA	NA	NA	NA	NA
WGPT (Degree-days) [a]	400	250	<250	-	400	250	<250	-	>250	<250	<250	<250	400	250	<250	-	>250	<250	-	-
AWHC (mm) [b]	90	60	30	<30	110	75	50	<50	150	110	75	<75	110	75	50	<50	110	75	50	<50
Soil depth (cm)	50	35	10	<10	100	70	40	<40	90	60	30	<30	100	50	25	<25	150	100	50	<50
Rill or Gully [c]	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Sheet/Wind/Undiff [c]	1,2	3	4	-	1,2	3	4	-	1,2	3	4	-	1,2	3	4	-	1,2	3	4	-
Slope (%)	<20	<40	<80	>80	<8	<12	<20	>20	<5	<8	<16	>16	<5	<8	<16	>16	<5	<8	<16	>16
Rock outcrop (%)	<20	<50	>50	-	<10	<20	<35	>35	<6	<10	<20	>20	<3	<5	<10	>10	<3	<5	<10	>10
Stone at surface (%)	<30	<60	>60	-	<20	<40	<60	>60	<20	<40	<60	>60	<6	<10	<20	>20	<6	<10	<20	>20
Stone content (%) [d]	<20	<50	>50	-	<10	<20	<35	>35	<10	<20	<30	>30	<6	<10	<20	>20	<6	<10	<20	>20

Source: MOA (1995); Mazahreh (1998); Hatten and Taimeh (2001), Ziadat (2007) with some modifications.
[a] Winter Growth Potential (Summation of degrees greater than 8 ºC during the coldest months); [b] Available Water Holding Capacity; [c] 1= Nil; 2= Slight; 3= Moderate, 4= Severe, [d] Stone content in the surface horizon.

use and management of land for the selected LUTs. Hatten and Taimeh (2001) and MoA (1995) aggregated the required land qualities and their characteristics into five main groupings – climate, soil, erosion, topography and rockiness. Table 1 presents the selected land use limitations, the land qualities, and land characteristics used to account for the effect of each land use limitation. Table 2 presents the selected land use types and their requirements in terms of land characteristics.

The main source of information for this study was obtained from the National Soil Map and Land Use Project (MoA, 1995). The data exists as paper maps, tables, and digitized information entered into the Jordan Soil and Climate Information System (JOSCIS). The most relevant data for this research are a detailed soil map at a scale of 1:10,000 that covers the study area (Mafraq), and 2193 soil observations (borehole or pit with known coordinates) that were collected during the soil survey. Pits were excavated to 200 cm, or to an obstructing layer. Soil descriptions were based on the FAO terminology (FAO, 1977). For each profile, the following soil attributes and site characteristics were collected:

- The limiting soil depth (depth to 200 cm or to rock or large stones).
- Slope percent (estimated using the Abbney level).
- Water holding capacity (calculated by considering the soil texture and depth of

each horizon and corrected to take account of stone and gravel contents).

- Erosion class (erosion severity observed in the field and classified as nil, slight, moderate, or severe).
- Erosion type (dominant types classified as nil, sheet, rill, gully, wind, or undifferentiated).
- Surface cover type (dominant type of non-soil material covering the surface classified as nil, rock, boulder, stone, gravel, or grit).
- Surface cover percentage (percent of the dominant surface cover type).

The evaluation procedure was based on the simple limitation system (FAO, 1976). This implies that land will be classified into one of the suitability classes (highly suitable (S1), moderately suitable (S2), marginally suitable (S3), or not suitable (NS)) based on the most limiting land characteristics, while the kinds of limitations that cause the suitability class are the basis for allocating sub-classes (Dent and Young, 1981). To undertake this classification, land characteristics (derived from soil observations or soil map units) were matched with the requirements for each LUT (Table 2) to assign land suitability classes – a matching process. A matching process is simply where the values of each land characteristic for each map unit or soil observation are compared with the requirements for each land utilization type. If the value is within the range accepted by the land utilization type, then the map unit or the soil observation is classified within the relevant suitability class. For example, according to Table 2, if the average precipitation for a map unit is 150 mm, then it will be classified as highly suitable (S1) for open range, but will be classified as moderately suitable (S2) for improved range. Two approaches were examined to accomplish the matching process. The first one calculated the average of the continuous variables and the mode of the ordinal variables for all field observations within each soil map unit. The calculated values (average or mode) were matched with the land use requirements for each land utilization type to assign a suitability class for each soil map unit (point-in-polygon analysis). IF statements (AND IF equations) (Omid, 2011) were used to classify each map unit based on the values of the land characteristics and using the limits between different suitability classes (Table 2). For example, IF “precipitation” is $\geq$ 100 AND “WGPT”$\geq$ 400 …etc., then classify as S1 for “open range”. The second approach started by assigning a suitability class for each individual soil observation by matching land attributes with land use requirements for each land utilization type, using AND IF statements. Spatial interpolation between observations was then used to generate suitability maps (for different LUTs). Since the interpolated variable is ordinal (suitability class), the Thiessen polygon (exact interpolator of nearest neighborhood) was used for this interpolation. This procedure is known as proximity analysis. It assigns the suitability rating of an observation point to the closest area to that point. This method was adopted to provide a detailed suitability map that utilizes all observations and, therefore, detects the spatial variability of the land characteristics. The suitability classification derived from this map was compared with that derived from the soil map.

The percentage of agreement between the suitability map and the suitability of the independent set of observation points (with known coordinates) for different LUTs was used to estimate the accuracy of the suitability maps derived using the average and mode approach (Shahbazi et al., 2010; Moradi et al., 2010). Area cross tabulation was used to compare suitability results derived by the spatial interpolation approach with those derived by the average and mode approach. Area cross tabulation enables a comparison of the percentage of the area where the suitability classification derived from the spatial interpolation method agrees with that derived from using the average of field observations within the soil map units.

RESULTS

A visual comparison of the suitability map derived using the average value of the field observations within the soil map units, with that derived using interpolation between observations (Figure 2) revealed some general agreement in the spatial distribution of the suitability classes. However, the map derived by interpolation shows a more detailed spatial distribution of different suitability classes. For example, the lower left side of the map is dominated by marginally suitable classes in the case of the suitability map derived using the soil map, whereas there is a balance between marginally and moderately suitable classes in the case of the map derived by interpolation. The latter even shows some highly suitable and not suitable areas. Using the average value of the observations within the soil mapping, the area of land classified as highly suitable was 0%, as moderately suitable was 7% (10.4 ha), as marginally suitable was 70% (103.6 ha), and as not suitable was 16% (23.6 hectare). The remaining 7% is urban area. Using spatial interpolation, the area of land classified as highly suitable was 1% (1.5 ha), as moderately suitable was 22% (32.6 ha), as marginally suitable was 48% (70.9 ha), and as not suitable was 22% (32.6 ha). These results indicate some differences in the extent and spatial distribution of suitability units using the two soil data interpretation approaches.

The overall accuracy is the sum of all observations for which the suitability classifications of the map agree with the classifications of the soil observations divided by the total number of observations. In Table 3, this equals to the sum of the diagonals (1714+47+23 in the case of open range) divided by the total number of observations (2068)–86%. Statistically, the overall accuracy of the suitability maps derived from the detailed soil map (scale 1:10,000) is different for the various land utilizations, ranging from 61% for drip irrigated trees to 88% for rainfed barley (Table 3). Generally, these results are in agreement with the accuracy figures reported for the same area (Mazahreh, 1998). Comparing the suitability of field observations with the suitability map reveals that a large number of observations within certain suitability map units are classified into other suitability classes.

The suitability maps derived from the average of observations within the soil map units were cross-tabulated with suitability maps derived from spatial interpolation (Thiessen polygons) for different land utilizations (Table 4). In this table, the diagonals represent the agreement between the two methods, while the overall agreement is the sum of the diagonal divided by the total. The overall agreements between the two methods (Table 4) are slightly lower than the agreements between the suitability maps and the suitability of individual observations

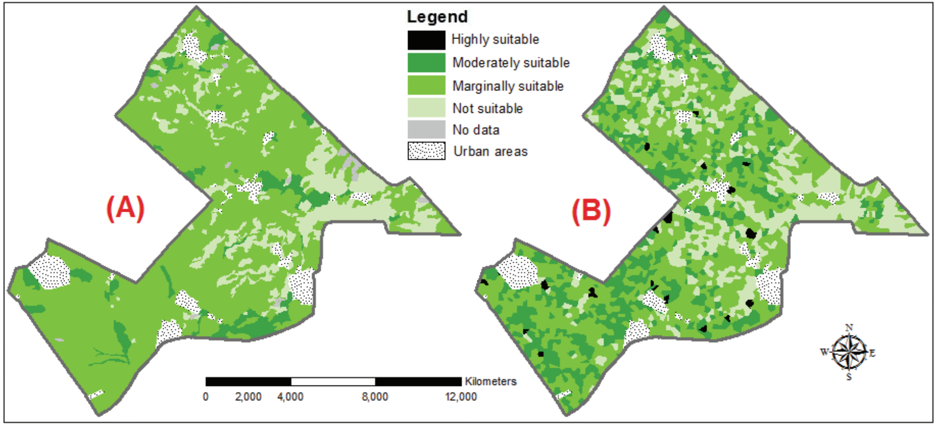

Figure 2. Suitability maps for drip irrigated trees derived using: (A) Average and mode of observations within soil map units, and (B) Interpolation using observations only.

Table 3. Agreement of suitability classifications derived from the detailed soil map with suitability derived for soil observations for different land utilizations.

	Suitability classes derived from maps													
Points suitability	Open range			Improved range			Rainfed barley		Drip irrigated vegetables			Drip irrigated trees		
	S2	S3	NS	S2	S3	NS	S3	NS	S2	S3	NS	S2	S3	NS
S1	-	–	–	-	-	–	-	-	-	-	-	5	16	1
S2	1714	45	1	1296	100	29	-	–	1052	153	33	57	440	16
S3	166	47	2	166	256	19	1659	57	162	221	60	74	923	59
NS	36	34	23	51	63	88	183	169	61	94	232	6	184	287
Overall Agreement	86 %			79 %			88 %		73 %			61 %		

Table 4. Agreement of suitability classifications (in percentages) derived from the detailed soil map with the suitability classification derived from observation interpolation (Thiessen polygons) for different land utilizations.

	Suitability classes derived from soil maps^a													
Thiessen polygons	Open range			Improved range			Rainfed barley		Drip irrigated vegetables			Drip irrigated trees		
	S2	S3	NS	S2	S3	NS	S3	NS	S2	S3	NS	S2	S3	NS
S1	-	–	–	-	-	–	-	-	-	-	-	0.2	0.8	0.8
S2	82.8	1.8	0.2	61.3	5.8	1.1	-	–	50.5	6.8	2.0	2.8	20	0.5
S3	8.9	1.8	0.2	10.5	10.4	1.2	79.2	3.1	9.5	8.9	3.4	4.1	43.9	4.2
NS	2.6	1.2	0.5	4.0	2.8	2.9	11.3	6.4	4.7	4.7	9.5	0.5	11	11.9
Overall Agreement	85 %			75 %			86 %		69 %			59%		

(Table 3). Again, it is remarked that the agreement between the two methods depends largely on the type of land utilization under consideration. The agreement is better for land utilizations that tolerate wider ranges of variation in land characteristics and which are more adaptable to the prevailing soil conditions (open range, improved range, and rainfed barley as compared with drip irrigated vegetables and trees). For example, all areas with slopes less than 20% are considered highly suitable for open range, while only areas with slopes less than 5% are considered highly suitable for drip irrigated trees (Table 2). In the latter case, the suitability classification is highly sensitive to small variations in soil attributes, resulting in lower agreements for both drip irrigated vegetables and trees. This result indicates that when the land use requirements become wider (using more adaptive crops), the suitability maps generated agree more with the field data. In other words, the suitability classification tolerates a wider range of variation in soil properties, resulting in a higher chance of agreement between the suitability classifications of the field observations and those of the map units. Riezebos (1989) indicated that when the suitability classes are narrowly defined and spatial variation is large, site suitability cannot be unambiguously determined. In order to verify this trend more clearly, a comparison was undertaken based on suitability sub-classes (by indicating the type of limitation for each map unit).

The results indicate that the area is generally moderately suitable (S2) for open range, improved range, and irrigated vegetables, while the land is either marginally suitable (S3) or not suitable (NS) for rainfed barley and irrigated trees (Table 5). The reason these classifications (types of limitation) vary for different LUTs is explained later. An obvious distinguishing feature of these results is the big difference in the suitability classification for each LUT between the map-derived classification and that derived using the Thiessen polygons. This reflects the efficiency of the two methods in detecting extreme values of the limiting land characteristics and, consequently, producing a different suitability classification (Figure 3). This will be discussed for each land utilization because the pattern depends on the LUT under consideration.

No land is classified as highly suitable (S1) for any land utilization except irrigated trees. This is because the winter growth potential temperature (WGPT) criterion for S1 is 400 degree-days, and the maximum WGPT in the study area is 387 degree-days. No land is classified as highly suitable or moderately suitable for rainfed barley. This is because the precipitation requirement to classify the land as S1 is 250 mm and as S2 is 200 mm, both of which are higher than the average annual precipitation in the study area (175 mm). A large part of the study area is classified as not suitable for drip irrigated trees mainly because of the shallow soil depth dominating the study area and the large extent to which the soil surface is covered with stones.

The results indicated good agreement in the suitability classification between the soil map-derived and the Thiessen polygon-derived suitability classifications for open range. Again, this is a result of the wide range of land characteristics required by this particular land use type. Consequently, the land is classified similarly regardless of the suitability calculation approach. For improved range,

Table 5: Land suitability classification according to the type of limiting factor derived from detailed soil map (Map) and from interpolation method (Thiessen).

	Area of suitability subclasses (%)									
Sub-	Open range		Improved range		Rainfed barley		Irrigated vegetable		Irrigated trees	
classes	Map	Thiessen	Map	Thiessen	Map	Thiessen	Map	Thiessen	Map	Thiessen
S1									0.0	1.0
S2c [a]	76.5	70.8	5.8	25.6			2.6	19.8		
S2ce	7.4	4.3	2.7	1.1			2.4	0.8		
S2cr	1.0	1.5	0.7	1.4			2.3	3.5		
S2cs	7.4	8.6	60.9	35.2			16.4	22.0		
S2cse	0.7	1.1	3.4	2.7			1.6	1.7		
S2cser	0.1	0.6	0.3	0.2			2.6	0.7		
S2csr	2.1	2.3	1.7	2.0			36.1	10.4		
S2csrt							0.5	0.7		
S2e							0.2	3.1		
S2se									2.6	18.7
S2ser									2.4	0.9
S2srt									2.3	3.2
S3c					74.7	67.5				
S3ce					0.2	2.8				
S3cs					15.6	11.9				
S3e	0.3	3.5	0.2	3.0					0.0	1.3
S3r							18.6	13.2	0.9	2.9
S3s	4.6	7.4	18.5	17.1			0.2	1.0	57.5	35.3
S3se			0.1	0.8					0.2	1.8
S3sr			0.4	1.3			1.6	4.4	17.4	11.0
NSr							12.0	11.0	7.4	7.7
NSs			5.2	8.8	9.3	16.2	0.5	1.7	2.3	6.3
NSsr			0.1	0.8	0.1	1.5	2.1	6.2	7.0	9.9

[a] Type of limitation: c, climate; s, soil; e, erosion; t, topography; and r, rock outcrop/stones.

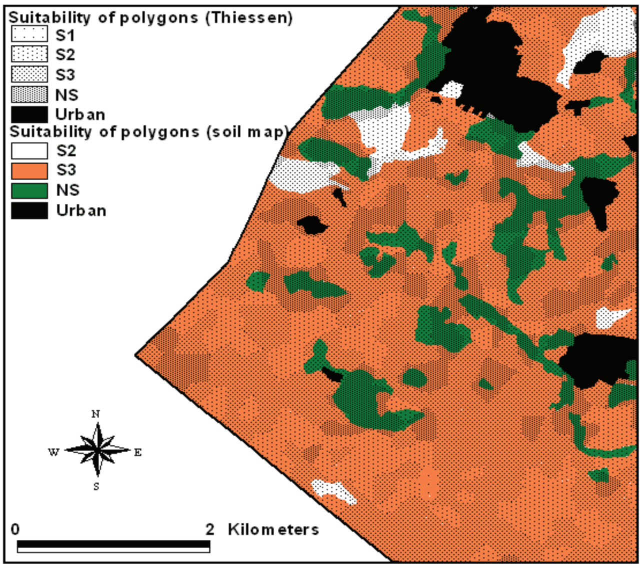

Figure 3. Comparison between suitability classifications derived from the detailed soil map with the suitability classification derived from observation interpolation (Thiessen polygons) for drip irrigated trees.

larger areas are classified as moderately suitable according to soil limitations when the average of the soil observations within the soil map units is used, while larger areas are classified according to climate and soil limitations when the interpolation method is used.

For rainfed barley, a larger area is classified as marginally suitable using the average of soil observations within the soil map units while a larger area is classified as not suitable using the spatial interpolation method. For irrigated vegetables, a larger area is classified, according to soil factors and rockiness, as moderately suitable when the average method is used, while larger areas are classified as marginally suitable and not suitable for irrigated vegetables using the spatial interpolation method. This means that the spatial interpolation method detects additional limitations compared to the average method. This agreed with the trend for improved range in that the Thiessen polygon method is more efficient in detecting slight variations in soil attributes as compared to the classification derived from the soil map.

For irrigated trees, a large area (76%) is classified as marginally suitable because of soil and rockiness limitations using the map-derived classification, while the spatial interpolation method indicated a relatively even distribution of the area into moderately (22.8%), marginally (52.3%), and not suitable (23.9%) classes (Table 5 and Figure 2). This effect is more obvious when the land use type requires extreme values of certain land characteristic, such as deep soil, as required for tree cultivation.

DISCUSSION

Traditionally, the suitability maps are derived by calculating an average (or modal) value of the various soil characteristics using many observation points within each map unit – that are known as Boolean models (Bello-Pineda *et al.*, 2006; Keshavarzi *et al.*, 2010). This process seems to pool the variations within one map unit and summarize them into one value, which results in suitability maps with low accuracy. Researchers indicated that the purity of soil map units is usually low, which leads to low quality for the derived suitability maps (Riezebos, 1989; Salehi *et al.*, 2003). Rilwani and Ikhuoria (2006) showed that the use of GPS observations to collect soil samples was better than the use of conventional agricultural land suitability maps for modern precision agriculture applications.

However, the density of observations plays an important role in this case. The Boolean operation used to undertake the suitability classification is the reason for the confusion, because a small difference in any soil attribute will place the land in a completely different suitability class (Ziadat, 2007). This effect becomes more obvious as the range of requirements for the LUT becomes narrower. The example presented in this study indicates that the lowest agreement figures are recorded for LUTs that require a stringent range of requirements and are associated with more inputs (drip irrigated vegetables and trees). The consequences of the incorrect location of these investments could be very costly.

The alternative to using the average values of the observations within the soil map units is to use interpolation between field observations, such as the nearest neighborhood interpolator (Thiessen polygons). This provides a better chance of representing the spatial variations in the land characteristics (Figure 2). However, estimating the accuracy of this method is not possible. This is an exact interpolator, the accuracy would be always 100%, because the observation will always be located at the center of the polygon and the suitability classification assigned for the polygon is based on the classification of that observation. Therefore, a separate set of observations is needed to evaluate the accuracy. However, the suitability maps derived using this method were compared to those derived from the soil map (the two maps in Figure 2) in order to understand the relative merits of these methods. Ziadat (2007) indicated that a comparison based on the intersection of polygons (those derived from suitability map units with Thiessen polygons) is better than using the individual observations. This is because using individual observations, the point will be considered either inside or outside the polygon, while the use of Thiessen polygons would allow consideration of the proportion of the area of each suitability class that is actually located within each suitability map unit, even when the point is outside the map unit.

The spatial interpolation method seems to be more efficient in distinguishing the types of limiting factors. This is because the spatial interpolation method retains the attribute of the points without any smoothing process, and gives this attribute to the neighborhood area of this point. For the map-derived suitability classification, the average of all observations within one map unit ignores these spatial variations and, consequently, produces a more general classification. Davidson (1992) indicated that the generalization of information within map units is not recommended, especially for large-scale mapping. Hence, the use of the Thiessen polygon approach seems to detect slight variations in soil attributes. Because the shape of the Thiessen polygon is determined from the spatial distribution of all neighboring observations, it could be postulated that this provides a better possibility to account for the spatial distribution of each suitability class derived from field observations. However, these relationships might change if the density of observations is less than what was used in this study (14 observations km^{-2}), i.e. if the distance between observations increased. The use of a lower density of soil observations (between 0.4 and 1.8 observations km^{-2}) resulted in a reduction of the accuracy of the suitability maps derived using the Thiessen interpolation (Ziadat, 2000). However, it can be argued that a reduction in the density of observations might also result in a similar reduction in the accuracy of the suitability maps derived from the soil maps.

A higher agreement between the map-derived and the Thiessen polygon-derived suitability maps was recorded for open range and rainfed barley as compared to irrigated trees (Tables 3 and 4). This is because the most important limiting factor for open range is climate (WGPT), and for rainfed barley it is the mean annual precipitation. The variations in the values of the WGPT and the mean annual precipitation are very low over this relatively small study area. In contrast, the lower agreement for irrigated trees is because the most important limiting factor is soil depth, and the variations in the soil depth values are high over the study area. Hence, the Thiessen polygon-derived maps seem to detect the variations in land characteristics, such as soil depth, over short distances better than the soil map.

Generally, the Thiessen polygon approach produced a more even distribution of the area either into suitability classes (highly, moderately, marginally and not suitable) or into suitability sub-classes (climate, soil, erosion, topography and rockiness). This means better detection of the spatial distribution of attributes and, consequently, better classification of soils into suitability classes. The irrigated trees case clarifies this because this particular land use requires an accurate detection of extreme values of the land attributes (deep soils). This agrees with findings reported by Van Kuilenburg et al. (1982) who indicated that the use of mean values within soil map units is less efficient than spatial interpolation methods in estimating soil moisture capacity. Therefore, the spatial interpolation method is more efficient than using the average of soil observations within the map units in detecting the spatial variability in land characteristic. In some cases, the reliability and accuracy of the suitability maps depend largely on the ability to detect extreme values of the land characteristics and their exact spatial distribution.

CONCLUSIONS

The quality of the suitability map depends on the approach to soil data interpretation. The area and spatial distribution of different suitability classes were different for suitability maps derived using the average of observations within the soil map units from those derived using spatial interpolation between field observations only. The quality of the derived suitability maps was also different for various LUTs. This is because of the difference in the limiting land characteristic for each land utilization type and the variation in the spatial distribution of each land characteristic over the study area. Generally, adaptable crops tolerate a wider range of variations in their land use requirements and, therefore, their suitability maps are more accurate than non-adaptable (introduced) crops with stringent land use requirements. The efficiency of the soil data interpretation approach in detecting the spatial distribution of the limiting land characteristics determines the accuracy of the suitability map. Thiessen polygon-derived suitability maps produced a more even distribution of areas among suitability classes and sub-classes, given the better detection of the spatial distribution of soil attributes and better detection of extreme values. Soil map-derived suitability classifications, using the average of soil observation within map units, seem to generalize the spatial variations and produced more clustered classifications. Extreme values of soil attributes are smoothed out using the latter approach and, therefore, were not detected for the suitability classification. This study points out that wherever detailed and reliable soil maps are not available, a spatial interpolation between intensive field observations is an alternative for producing reliable suitability maps. However, the sensitivity of these maps to the density of, and distance between, observations must be considered.

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مقایسه دو روش تفسیر داده‌های خاک به منظور بهبود قابلیت اطمینان از ارزیابی مناسب بودن زمین

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چکیده

مدیریت پایدار آب و منابع محدود برای پاسخگویی به افزایش تقاضا برای غذا و حفاظت از محیط زیست ضروری می باشد. تجزیه و تحلیل مناسب بودن زمین، پیش نیاز ارزیابی و ارائه جایگزین‌های پایدار کاربری اراضی برای یک منطقه است. داده‌های خاک معمولا در سطوح مختلفی از جزئیات و در اشکال مختلف، معمولا به شکل نقشه خاک و یا مشاهدات خاک در دسترس هستند. روش تفسیر داده‌های خاک، قابلیت اطمینان از نتایج ارزیابی مناسب بودن زمین را کنترل می کند. این امر تاثیر جدی بر روی قابلیت اعتماد نقشه‌های مناسب بودن زمین، تصمیم گیری‌های بعدی کاربری اراضی، و مدل سازی محیط زیست دارد. این مطالعه به بررسی قابلیت اطمینان تهیه نقشه مناسب بودن زمین با استفاده از روش‌های مختلف تفسیر داده‌های خاک – متوسط ویژگی‌های زمین برای مشاهدات میدانی در داخل واحدهای نقشه خاک (نقطه در چند ضلعی) و درون یابی فضایی با استفاده از تنها مشاهدات زمینی (نزدیکی به نقطه) می پردازد. درجه توافق بین دو روش بستگی به نوع استفاده از زمین – جو دیم (۸۶٪)، مرتع باز (۸۵٪)، مرتع اصلاح شده (۷۵٪)، سبزیجات آبیاری قطره‌ای شده (۶۹٪)، و درختان آبیاری قطره‌ای شده (۵۹٪) دارد. این امر به دلیل تفاوت در مشخصه‌های زمینی محدود کننده که تعیین کننده مناسب بودن هر نوع بهره وری از زمین هستند و الگوی تغییرات فضایی هر مشخصه زمین می‌باشد. نقشه مناسب بودن زمین برای محصولات سازگار (بومی) (مانند جو و محصولات مرتعی)، که نیاز به ورودی‌های زراعی حداقل دارند، معمولا به دلیل طیف وسیع‌تر تحمل تغییرات درآنها، دقیق تر است. روش درون یابی در شناسایی توزیع فضایی و مقادیر مفرط محدود کننده ویژگی‌های زمین، کارآمدتر بوده و در نتیجه نقشه‌های دقیق تری به دست می‌دهد. بنابراین، هنگامی که نقشه‌های دقیق خاک در دسترس نباشند، می‌توان از مشاهدات میدانی با استفاده از روش درون یابی دقیق، نقشه مناسب بودن زمین را تهیه نمود.