

Climate change impact on land capability using MicroLEIS DSS

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Received June 30, 2008; accepted August 5, 2008

A b s t r a c t. The effects of climate change on land capability are compared for two cultivation methods (irrigated and rainfed) in a semi-arid region – Ahar (East Azarbaijan, IRAN). Two models: Terraza and Cervatana, included in the land evaluation decision support system called MicroLEIS DSS, were used. While Terraza gives a quantitative prediction of the bioclimatic deficiency of a site, Cervatana forecasts the general land use capability or suitability for a broad series of possible agricultural uses. A future scenario of climate change was calculated according to the Intergovernmental Panel on Climate Change (IPCC) on regions of Asia under scenario A1 (highest future emission) for 2080s. The results showed that climate change is likely to cause severe water stress in irrigated cultivation of alfalfa, sugar beet, potato, and maize, being the use of irrigation methods essential to maintain the agricultural productivity. However, the land capability classification for wheat crop in the future scenario will remain constant. Although irrigation is indicated as very important in this semi-arid agriculture, cultivation of rainfed wheat can be possible instead of the irrigated cultivation. In summary, this modelling application approach predicts that yield reduction of the selected crops, in rainfed and irrigated conditions, will increase by 18 and 13%, respectively.

K e y w o r d s: climate change scenario, land capability evaluation, MicroLEIS DSS, semi-arid climate, yield reduction

INTRODUCTION

The general scientific consensus is that a significant climate change will occur during the next 100 years, although there remain quantitative uncertainties in the climate models. This climate change will not occur without marked impacts upon various sectors of our environment, and consequently of our society (Chavas *et al.*, 2009). Climate changes in the semi-arid regions will appear which will have an important impact on soil capability. Crop simulation model-

ling studies based on future climate change scenarios indicate that substantial losses are likely in rainfed wheat in South and South-East Asia (Fischer *et al.*, 2002). For example, a 0.5°C rise in winter temperature would reduce wheat yield by 0.45 t ha⁻¹ in India (Kalra *et al.*, 2003). Climate change can affect other parameters, such as land degradation risks in agricultural areas, soil erosion, and contamination. Increased land degradation is one possible, and important, consequence of global climate change. Therefore, the prediction of global environmental change impacts on these degradation risks is a priority (De la Rosa, 2008; De la Rosa *et al.*, 1996).

It is estimated that a minimum cropland area of 0.5 ha/person is required to provide an adequate diet (Lal, 1989). Of course, this makes certain assumptions about the climate and soil conditions, and about the level of technology used. Agricultural management systems located on the most-suitable lands, depending on their agroecological potentialities and limitations, constitute the first step to achieving soil sustainability which has resulted in Ahar region as a land use planning without attention to the climate change impact (Shahbazi *et al.*, 2008). Contrarily, any kind of agricultural management system will have a negative environmental impact when applied on land with very low suitability for agricultural uses.

MicroLEIS DSS application and climate change impact in two semi-arid and Mediterranean regions showed that alfalfa has 40 and 50% of yield reduction respectively in Ahar and Sevilla area, and this coefficient will increase 10% by climate change. Also, maize has 70 and 35% of yield reduction, respectively in Ahar and Sevilla area, and this coefficient will increase 20% by climate change.

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To date, in Iran, high technology in information and knowledge was not a common tool for evaluating land capability and suitability except the last investigations by using MicroLEIS DSS in Ahar (Shahbazi *et al.*, 2009a) and Souma area with attention to some natural phenomenon such as climate change (Shahbazi *et al.*, 2009b). However, land evaluation results from a complex interaction of physical, chemical, and bioclimatic processes and evaluation models are reliable enough to predict accurately the behaviour of land (Ball and De la Rosa, 2006; CEC, 2004; Held *et al.*, 2003). As land evaluation focuses on global change, this methodology could be used to investigate the impact of climate change on potentialities and vulnerabilities of the land. The fundamental purpose of land evaluation is to predict the positive or negative consequences of change. Land evaluation can be a formal, structured method to assess land degradation risks caused, for example, by long-term changes in climatic conditions and/or agricultural systems.

On the other hand, decision support systems (DSS) are informatics systems that combine information from different sources; they help in the organization and analysis of information, and also facilitate the evaluation (Eom *et al.*, 1998; Sauter, 1997). In this conceptual framework was developed the land evaluation decision support system MicroLEIS DSS (De la Rosa *et al.*, 2004; 2009). The MicroLEIS DSS system, through its 12 land evaluation models, analyzes the influence of selected soil indicators on critical soil functions referred to: 1) land productivity (agricultural and forest soil suitability, crop growth, and natural fertility), and 2) land degradation (runoff and leaching potential, erosion resistance, subsoil compaction, workability, and pollutant absorption and mobility). These knowledge-based models were basically developed as sophisticated tools based on artificial intelligence techniques. Input variables are physical/chemical soil parameters *eg* useful depth, stoniness, texture, water retention, reaction, carbonate content, salinity, or cation exchange capacity collected in standard soil surveys, monthly agroclimatic parameters for long-term period, and agricultural crop and management.

The main objective of this work is to distinguish the best agricultural lands from the marginal ones, and to predict the impacts of climate change on the lands in Ahar area. By using MicroLEIS DSS (De la Rosa *et al.*, 2004; 2009), a land evaluation analysis was developed to calculate bioclimatic deficiency and land capability of these soils, and for two hypothetical climate scenarios: current and future. This work also focuses on agricultural management changes, in rainfed and irrigated conditions, to mitigate the negative climate impact and achieve sustainable agriculture in the long term.

MATERIALS AND METHODS

This study was performed in the Ahar province of East Azarbaijan, Iran, which has different kinds of land use associated with soils of different parent material, such as limestone, old alluvium, and volcano-sedimentary rocks. It

covers about 9000 ha, between 47°00'00" to 47°07'30" East and 38°24'00" to 38°28'30" North. Its slopes range from <2 to 30%, and the elevation is from 1 300 to 1 600 m above sea level. Flat, alluvial plain, hillside, and mountain are the main physiographical units in the study area. A detailed soil survey under soil family category was followed in the Ahar study area, of about 9 000 ha of extension, which is summarised in the soil map shown in Fig. 1. A total of 44 soil profiles were characterized in the field and the lab, determining standard morphological, physical and chemical variables. According to the USDA Soil Taxonomy (2006), the dominant soils are classified as Inceptisols, Entisols, and Alfisols. Additionally, 10 soil subgroups and 23 soil families were obtained. Typic Calcixerepts is the major subgroup (> 53% area). The location of the study area accompanied with soil family covered is shown in Fig. 1.

The multilingual soil database SDBm Plus (De la Rosa *et al.*, 2002) was used to store and manipulate this large amount of soil data. The input data were the following: field site descriptions and soil profile characteristics; standard soil analytical data and soluble salts data; and soil physical analytical data, especially with reference to infiltration and water retention. Major facilities of SDBm plus include input, edit, print, selection, and file generation. The 'soil layer generator' option provides a useful interface between SDBm plus and the land evaluation and geographic information systems. The control section for applying the Cervatana model was between 0 and 50 cm. Physical and chemical analysis report is summarised in Table 1.

Climate data, such as mean average maximum and minimum temperatures for each month and total annual precipitation for last 20 consecutive years (1986-2006), were collected from Ahar meteorological station (Shahbazi *et al.*, 2008). These data were integrated in the CDBm database (De la Rosa *et al.*, 1986). Climate observation at a particular meteorological or weather station is the essence of the Monthly Climate Database CDBm, a major component of MicroLEIS DSS (De la Rosa *et al.*, 2004). The mean values of such records for more than 10 days (20 consecutive years) are considered climatic magnitudes. It is precisely by a period of time that meteorology is distinguished from weather. The basic data of CDBm are the mean values of the daily dataset for a particular month. Climate data, such as mean maximum and minimum temperatures, and total annual precipitation, are input variables in CDBm to calculate potential evapotranspiration using two methods: Thornthwaite (1948) and Hargreaves *et al.* (1985). Results of CDBm program calculations for two hypothetical scenarios are shown in Table 2.

The Intergovernmental Panel on Climate Change (IPCC) refers the climate change to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). It refers to any change in climate over time, whether due to natural variability or as a result of human activity. The projected temperature increase is widespread over the globe,

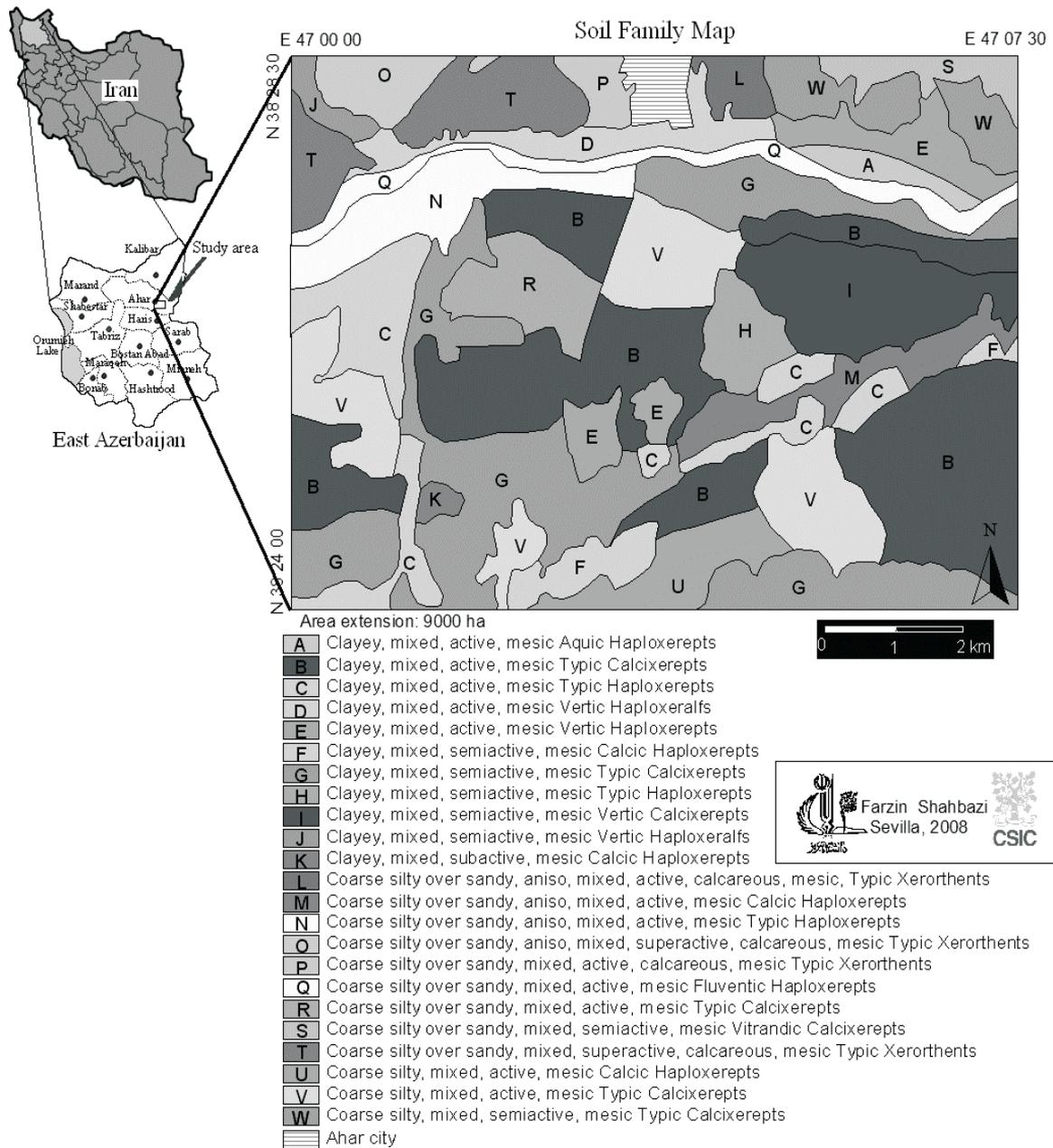


Fig. 1. Soil family covered in the study area.

and is greater at higher northern latitudes. All of Asia is very likely to warm up during this century; the warming will probably be well above the global mean in west Asia (Christensen *et al.*, 2007). In order to apply the land evaluation approach, two climate change scenarios were constructed. The first was defined by the climate over the last 20 years (1986-2006) (Table 2). The second scenario is based on projected changes in surface air temperature and precipitation for west Asia under the highest future emission trajectory (A1FI) for the 2080s (IPCC, 2007). Following the IPCC report, the mean temperature (°C) will increase by 5.1, 5.6, 6.3 and 5.7 in winter, spring, summer and autumn, respec-

tively, in the future scenario at the study area. On the other hand, total precipitation will decrease by 11 and 25% in winter and spring, while it will increase by 32 and 52% in summer and autumn. It is estimated that the agricultural irrigation demand in arid and semi-arid regions of Asia will increase by at least 10% for an increase in temperature of 1°C (Fischer *et al.*, 2002; Liu, 2002). In the study area, climate change is likely to cause severe water stress in the 21st century because of the decreasing of precipitation in the growing season, and water management will be increasingly important. Results of CDBm program calculations for the two hypothetical scenarios are shown in Table 2.

Table 1. Summary of major soil variables* of the soil types characterized in Ahar study area

USDA soil subgroups	Useful depth (cm)	Soil physical properties				Soil chemical properties				
		Texture	Coarse fragment (%)	Bulk density (g cm^{-3})	Water capacity (cm)	Carbonate content (%)	Organic carbon (%)	ESP (%)	EC (dS m^{-1})	pH
Aquic Haploxerepts	130	Clay loam	1.30	1.10	14.09	11.36	1.01	4.21	2.47	8.14
Calcic Haploxerepts	147	Clay	7.16	1.42	13.55	19.65	0.91	2.54	1.52	8.26
Fluventic Haploxerepts	119	Sandy clay loam	22.76	1.37	17.91	10.26	0.30	6.00	0.77	8.71
Typic Calcixerepts	151	Clay loam	10.92	1.33	12.99	18.31	0.61	2.14	1.49	8.23
Typic Haploxerepts	128	Clay loam	6.40	1.26	13.46	14.80	0.84	1.82	0.95	8.27
Vertic Calcixerepts	140	Clay	4.00	1.25	14.58	17.87	0.50	3.10	1.25	8.42
Vertic Haploxeralfs	185	Clay	0.80	1.23	11.50	13.80	0.97	5.36	2.10	8.48
Vertic Haploxerepts	135	Clay loam	12.78	1.54	11.35	14.58	0.76	3.72	2.00	8.32
Vitrandic Calcixerepts	150	Clay	12.26	1.34	9.72	14.91	0.33	1.32	0.70	8.46
Typic Xerorthents	62	Sandy clay loam	10.80	1.50	10.50	6.82	0.74	1.07	1.00	7.90

*Mean value of selected parameters measured in the topsoil (0-50 cm), ESP – exchangeable sodium (%), EC – electrical conductivity.

Table 2. Summary of climate database results of Ahar station for two hypothetical scenarios

Variables	Mean temperature ($^{\circ}\text{C}$)	Precipitation (mm)	ET_o (mm)	Humidity index	Aridity index	Growing season	Arkley index
Current scenario	10.8	299.4	660.3	0.45	6	8	76.1
Future scenario	16.5	307.4	846.9	0.36	7	11	52.6

ET_o – potential evapotranspiration.

The semi-arid region is characterized by seasonal distribution of precipitation, with summers more or less dry; this situation is not very suitable for crop growth. Therefore, most agricultural production systems depend basically on irrigation water as an available water resource. The amount of water for irrigation of the selected crops in Ahar province ranges between 3 100 and 6 800 $\text{m}^3 \text{ha}^{-1}$, with 35% water use efficiency (Farshi *et al.*, 1997). The number of irrigations in the growing period is 4-8. Table 3 summarises the present water management conditions for the study area.

MicroLEIS DSS (De la Rosa 2004; 2009) is a decision support system for scaling-up process knowledge from micro-scale to a landscape scale, such as regional scale. Currently, socio-economic attributes are not considered. MicroLEIS DSS has evolved significantly towards a user-friendly agro-ecological decision support system for environmentally sustainable soil use and management. The design philosophy is a toolkit approach, integrating many software instruments:

databases, statistics, expert systems, neural networks, Web and GIS applications, and other information technologies. Through its 2 land evaluation models, Terraza and Cervatana, it analyzes the influence of selected soils on land potentialities attention to climate perturbations.

The Terraza model, as a component of MicroLEIS DSS (De la Rosa *et al.*, 2004; 2009), predicts the bioclimatic deficiency of a site mainly from climatic factors and certain others of the plant and soil, so that the evaluation of a single land unit (climate and soil) may differ depending on the current use (crop). In general terms, the criteria followed are those established by the FAO (1976), with some adaptations.

This bioclimatic classification begins by determining the monthly potential evapotranspiration (ET_o), using the method of Thornthwaite (1948), from the monthly mean temperature (T_m), and the monthly coefficient of light correction (N_m) depending on the site latitude. The monthly evapotranspiration of the crop (ET_c) is calculated from ET_o as follows:

Table 3. Water irrigation supplements for the major crops in the present climate conditions from Ahar study area (Farshi *et al.*, 1997)

Crop	Irrigation (m ³ ha ⁻¹)	No. of irrigations	Irrigation months	Sowing date (months)
Wheat (<i>Triticum aestivum</i>)	3 100	4-6	X, XI, V, VI, VII	X
Alfalfa (<i>Medicago sativa</i>)	6 800	7-8	X, V, VI, VII, VIII, IX	V
Sugar beet (<i>Beta vulgaris</i>)	6 300	5-7	V, VI, VII, VIII, IX	XI
Potato (<i>Solanum tuberosum</i>)	5 500	4-5	V, VI, VII, VIII, IX	V
Maize (<i>Zea mays</i>)	5 500	4-6	V, VI, VII, VIII, IX	V

$$ETc = ETo Kc, \quad (1)$$

where: Kc – monthly coefficient of the crop; the monthly real evapotranspiration (ETA) is given by:

$$ETA = ETc - D, \quad (2)$$

where: D – monthly water deficit of the site.

The difference between monthly evapotranspiration and precipitation at a site can be positive or negative. If positive, there is a surplus or excess (S) of water; if negative, there is a deficit or lack (D). During the seasonal period of a crop, this difference is calculated between the precipitation and evapotranspiration of the crop (ETc).

Then, the monthly reduction in crop production (Ry) is calculated using the following formula:

$$1 - Ya/Ym = Ky(1 - ETA/ETc), \quad (3)$$

substituting

$$1 - Ya/Ym = Ry, \quad (4)$$

we have:

$$Ry = Ky(1 - ETA/ETc) \times 100 \text{ (expressed as \%)} \quad (5)$$

where: Ya – real crop production, Ym – potential crop production, Ky – coefficient of efficiency of the crop.

The coefficients Kc and Ky are determined using works of the Doorenbos and Pruitt (1977) which establish the different phenological periods of various crops with different management levels (extensive, intensive or moderate).

Finally, the annual reduction in crop production (Rys) is calculated as follows:

$$Rys = Kys (1 - \Sigma ETA / \Sigma ETc) 100 \quad (6)$$

where: Kys – coefficient of seasonal reduction, ΣETA – sum of the monthly real evapotranspiration during the phenological period of the crop, ΣETc – sum of the monthly evapotranspiration of the crop during its phenological period.

In this research, the variable parameters were climate data for current scenario (1986-2006) and for the 2080s. Calculation of the bioclimatic classification and percentage of yield reduction begins by determining the monthly potential evapotranspiration (ETo), using the method of Thornthwaite. Soil water retention capacity for all soil types was variable from 7.3 to 17 cm; the mean value was applied to run the Terraza model. Crop coefficient and yield response factor of the crops were as given by FAO (1976). Within the model it is possible to define any arbitrary set of climate perturbations as the hypothetical climate change. For example, maximum and minimum temperature (°C) and precipitation (%) are climate-related factors that could be applied as climate change by increment (+ or -). The water irrigation amount (cm) can be considered a precipitation factor. Yield reduction of wheat, alfalfa, sugar beet, potato, and maize – in either rainfed or irrigated cultivation for two comparable scenarios – was calculated.

The Cervatana model, as a component of MicroLEIS DSS (De la Rosa *et al.*, 2004; 2009), predicts the general land use capability for a broad series of possible agricultural uses. As shown in Fig. 2, the data requirements can be grouped in the following biophysical factors: relief, soil, climate, and current use or vegetation. This qualitative model works interactively, through different gradation matrixes, comparing the values of the input characteristics of the land unit to be evaluated with the generalization levels established for each capability class. The first three classes – S1, S2, and S3 – include land considered able to support continuing, intensive agricultural use, while land of Class N is more appropriate for natural or forestry use.

Through the integration of MicroLEIS DSS with GIS techniques, it is possible to expand land evaluation results from point to geographic areas, using soil survey and other related maps. Arc View GIS was used in this research work to show Cervatana model results by long-term changes in climatic conditions and/or agricultural systems. To this geographic level of assessment is where policy decision is usually made (De la Rosa *et al.*, 2009; Martinez, 2009; Willems *et al.*, 2008). The potential capability classification was made for both rainfed and irrigated cultivations.

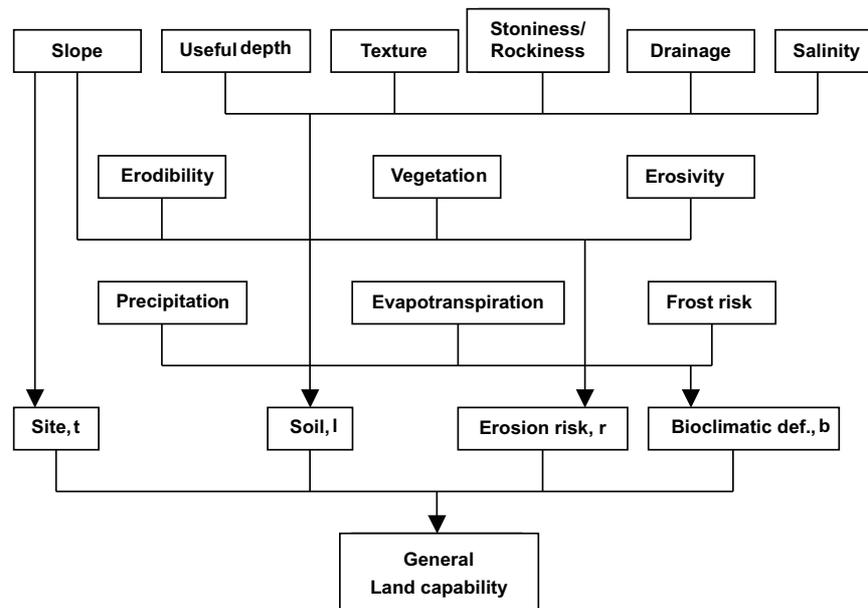


Fig. 2. General scheme of the Cervatana model.

RESULTS AND DISCUSSION

Graphical representation under climate change impact for hypothetical future scenario using CDBm database system is shown in Fig. 3. Comparing with the current scenario (Shahbazi *et al.*, 2008), in the long term, annual average of temperature, precipitation and evapotranspiration will be increased by 5.7°C, 12 and 28%, respectively, by climate change. This means that in the far future, erosivity can decrease, despite rainfall, and the main problem for agricultural land use will be drought.

The bioclimatic deficiency was calculated applying the Terraza model, for the major crops in Ahar area: wheat, alfalfa, sugar beet, potato and maize.

In the current scenario, the Terraza modelling approach predicts that wheat has 0% (H1 class) of yield reduction in both rainfed and irrigated cultivations. The usual irrigation in the study area (Table 3) for potato and alfalfa is sufficient, increasing their bioclimatic classes from H3 and H2 to H1. Sugar beet and maize currently have 57 and 72% yield reduction of production, while this reduction will decrease to 23 and 20%, respectively, for the selected crops.

In rainfed cultivation, yield reduction of production for wheat, alfalfa, sugar beet, potato, and maize is increased 17, 19, 14, 22, and 20%, respectively, as a result of climate change, while for the irrigated condition, these parameters were calculated as 0, 4, 13, 25, and 28%, respectively. Applying the usual irrigation, the amount of water is sufficient for wheat, alfalfa and sugar beet, but for potato – and especially for maize – it is inadequate. Using new and classic irrigation methods can be recommended to increase the water use efficiency and decrease the yield reduction of production (Fig. 4).

The Terraza model approach predicts that the currently high water deficit in the study area will be increased as a result of climate change by the 2080s for all the crops except wheat. Although irrigation is indicated as very important in this semi-arid agriculture, results show that cultivation of rainfed wheat is possible in order to reduce the tillage operation costs.

The land capability was evaluated, soil by soil, applying the Cervatana model in the 9 000 ha of Ahar area. This land evaluation analysis was developed for the current and future climate scenarios, and for rainfed and irrigation conditions.

For the two hypothetical scenarios (the current situation and the 2080s) it was showed that wheat crop in all the simulated conditions has the same land capability classification. As shown in Table 4, 41.7, 45.6, and 11.7% of the total area presents excellent (S1), good (S2), and moderate (S3) capability classes, respectively. Soil limitation was the main factor for converting the capability class from excellent to good. The bioclimatic limitation factor (b) was not determined in the cultivation of wheat. Therefore, the capability classes will not be changed in the long-term scenario.

With climate change, 45.6% of the total area for alfalfa has been changed from good- to moderate-capability land. The same area for potato and sugar beet has been changed from good- to moderate-capability land. The whole area was not suitable in either the current situation or the 2080s for maize. Bioclimatic deficiency was the most-limiting factor.

Finally, concerning soil evaluation, eight application soil subgroups are classified as arable or best agricultural lands, and other two as moderate lands under rainfed condition. Typic Calcixerepts, Typic Haploxerepts, Vertic

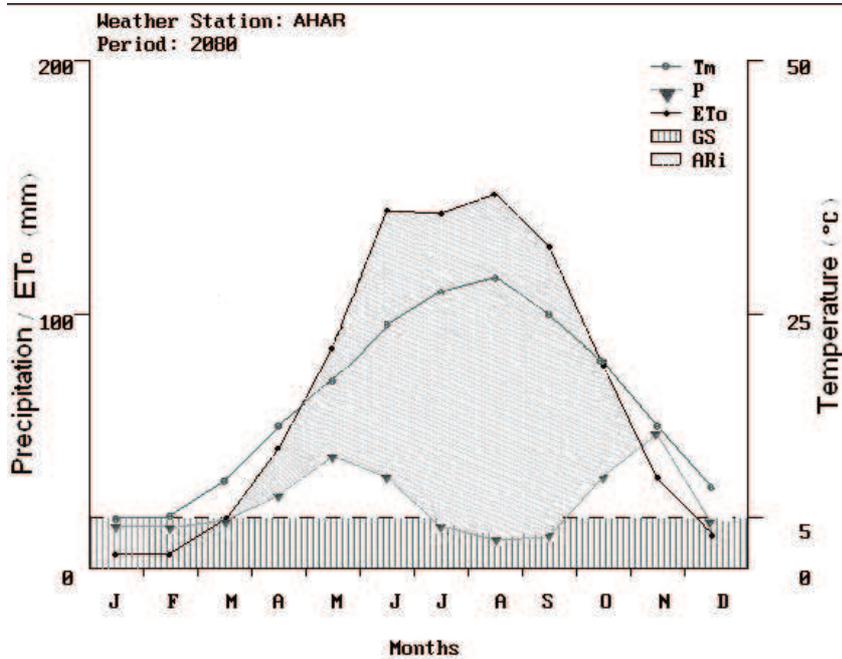


Fig. 3. Graphical representation of climate information by climate change. *Tm* – mean temperature, *P* – precipitation, *Gs* – growing period, *Eto* – potential evapotranspiration, *Ari* – aridity index.

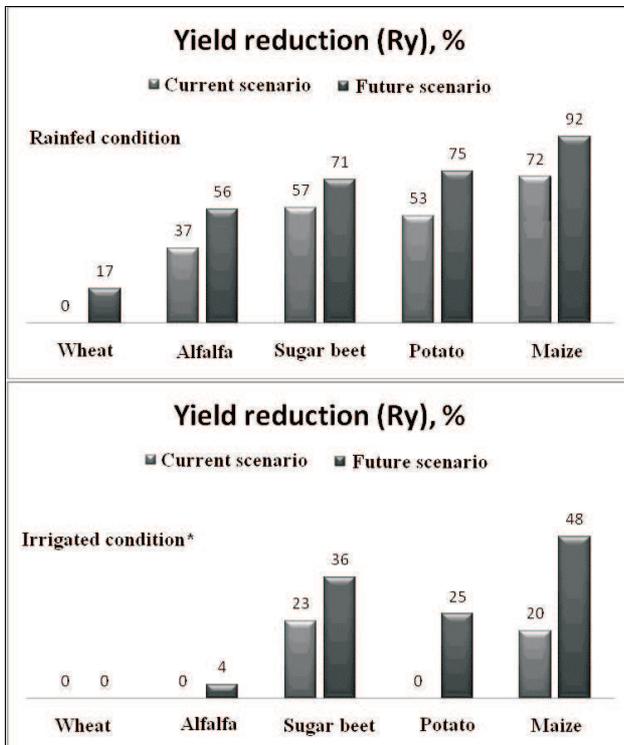


Fig. 4. Yield annual reduction for cultivation of irrigated and rainfed conditions comparing two scenarios. *Water irrigation supplement based on usual amount in the study area (see Table 3).

Calcixerepts, Vertic Haploxeralfs, Calcic Haploxerepts, and Vertic Haploxerepts present an extension of 22.8, 7, 5.6, 3.1, 1.83, and 1.43%, respectively, of S1 class for most of the crops. Soil and topography limitations are the two basic factors in classifying the Fluventic Haploxerept and Vitrandic Calcixerept subgroups as moderate lands that are currently dedicated to agricultural use. The change in these last two soil subgroups from natural habitat to intensively tilled agricultural cultivation is one of the primary reasons for soil degradation. Land use will be taken as optimum when considering the moderate arable lands as a natural habitat cultivation area. However, 45% of the study area is classified by the soil limitation factor as good-capability land. The general land capability classification integrated with GIS and soil subgroups is summarised in Table 4.

The land capability classification for irrigated cultivation using the normal water amount associated with 35% water use efficiency is divided in two sets: Dense cover (wheat and alfalfa) and moderate cover (sugar beet, potato, and maize). The first group presents similar capability classes to that for rainfed cultivation of wheat.

Sugar beet cultivation showed no response to climate change concerning the constant bioclimatic deficiency class (H2), so 87.3% was good agricultural land and the rest was moderate agricultural land. The major limitation factors in classifying the capability of the area were bioclimatic and erosion risks which were constant with climate change. The results showed that bioclimatic deficiency is the main agent in decreasing the capability classes in irrigated cultivation of potato and maize.

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Table 4. Cervatana model (MicroLEIS DSS) results: extension of land capability classes (ha), under rainfed condition

USDA soil family *	Approx. extension (ha)	Land capability classes for hypothetical scenarios													
		Current situation							Future scenario						
		S1	S2l	S2lr	S2tl	S2tr	S3l	S3t	S2b	S2lb	S2lrb	S2tlb	S2trb	S3l	S3t
A	89.1	89.1						89.1							
B	1971	1 035		176				760	1 035			176			
C	626.4	626.4						626.4							
D	214	214						214							
E	326.8	198.1						128.7	198.1						
F	156.5	22.4						134.1	22.4						
G	1471.8	620.3		110			218	523.5	620.3		110			218	
H	165	165							165						
I	522.2	522.2						522.2							
J	64.5	64.5						64.5							
K	30	30						30							
L	93		93										93		
M	246		246										246		
N	340	340							340						
O	164		164										164		
P	82					82								82	
Q	262					262								262	
R	220	220													
S	141.7						141.7								141.7
T	409.1	55.1				354			55.1					354	
U	237.3	237.3							237.3						
V	808.3	547.3	261					547.3	261						
W	277.3	277.3							277.3						

Limitation factors: t – topography, slope type and slope gradient; l – soil: useful depth, texture, stoniness/rockiness, drainage, and salinity; r – erosion risk: soil erodibility, slope, vegetation cover, and rainfall erosivity; b – bioclimatic deficiency. *Soil family classification based on Fig. 1.

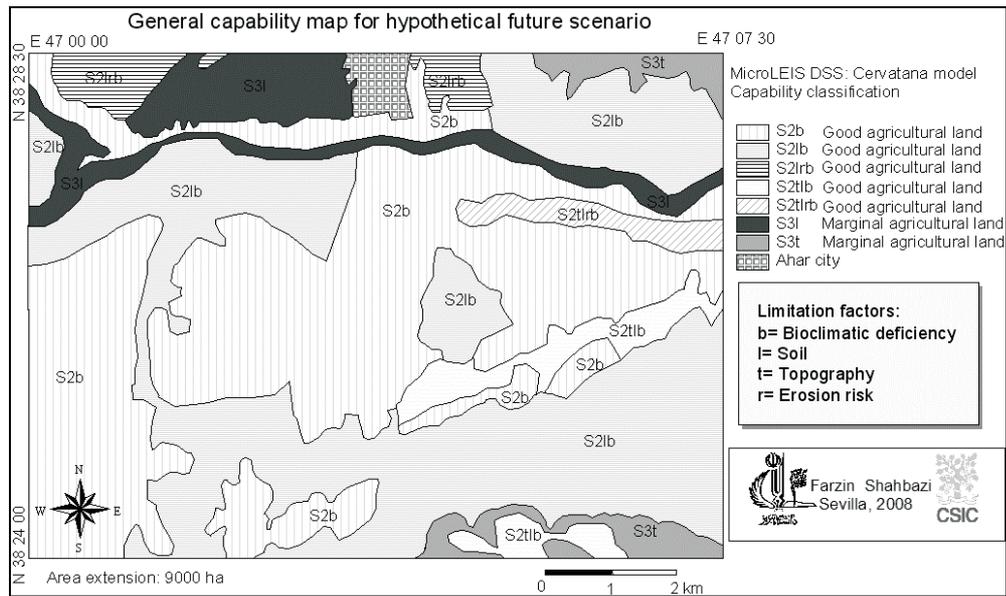


Fig. 5. General capability map of study area, integrating GIS and Cervatana model results for hypothetical future scenario.

Spatialization or regionalization analysis includes the use of spatial techniques to expand land evaluation results from point to geographic areas, using soil survey and other related maps. The use of geographic information system (GIS) technology leads to the rapid generation of thematic maps and area estimates, and enables many of the analytical and visualization operations to be carried out in a spatial format, by combining different sets of information in various ways to produce overlays and interpreted maps. This technology is already a prerequisite for managing the massive datasets required for spatial land evaluation application – a simple map subsystem *eg* ArcView being all that is required to show basic data and model results on a map, or to extract information from maps to be used in the land evaluation models. In the present work, results from the Cervatana model were combined with GIS (ArcView 3.2) in order to develop a computerized spatial database with the aim of suggesting suitable land management strategies for environment conservation; as a result the general capability map of study area for hypothetical future scenario that is shown in Fig. 5 was obtained.

Testing analysis involves comparison of outputs of MicroLEIS DSS models with real information and determination of the DSS suitability for the intended purpose. Real information represents field data on the aspects for which the models are being tested. During the modelling development phase, each model was already validated, including generally calculation of standard errors, root mean square error, slope and intercept of regression, and correlation of observed vs. predicted results (De la Rosa *et al.*, 2004; 2009). Also, other scientists have tested the models over diverse regions exposing models to new and different environments and testing model robustness (Machin and Navas, 2007).

Therefore, comparing the results of model application with the real condition of arable areas showed that MicroLEIS DSS can be used in this semi arid region with special reference to its high accuracy in the current situation. The predicted land capability values were simulated by extrapolation from benchmark site results applying the Cervatana model to the corresponding natural region. The relationship between predicted land capability and present land use from statistical records is clearly unbalanced. About 250 000 ha of rainfed agricultural lands must be changed to forestry, grazing or natural lands in order to get a better equilibrium in comparison with the moderately or clearly marginal lands. Similar situations are very frequent in the Mediterranean region, and it is, for example, the major reason for the reforestation program launched by the European Commission.

CONCLUSIONS

1. Land evaluation appears to be a useful way to develop the potential and/or general capability to distinguish the best agricultural land resulting from interactive changes in land use and climate. In Ahar, 45% of the total area was classified as good-capability land for agricultural uses, for the current climate. However, almost 12% of the total area (including Fluventic Haploxerepts, Vitrandic Calcixerepts, and some parts of Typic Calcixerepts and Typic Xerorthents) is classified within Class N, what is more appropriate for natural or forestry use.

2. Bioclimatic deficiency is the most-sensitive factor affected by climate change. For rainfed conditions, the yield reduction increases with climate change for all the studied crops, as follows: wheat < alfalfa < sugar beet < potato < maize, however, for irrigation conditions, the yield reduction is alfalfa < potato < sugar beet < maize.

3. Nevertheless, irrigation is indicated as very important in this semi-arid agriculture; the cultivation of rainfed wheat can be recommended instead of the cultivation of irrigated wheat to reduce the tillage operation costs.

4. Climate perturbation effects on rainfed conditions are higher than on irrigated conditions. Irrigated maize and potato will be affected more than the other studied crops in the future scenario. The general capability classification, with special reference to the wheat crop, is constant in the two comparable scenarios. The slope and the soil depth are the major limitation factors in this agroecological zoning classification.

5. As climate change is likely to cause severe water stress in the 21st century, water management will be increasingly important. The use of modern irrigation methods can be recommended for the Ahar area in the future.

6. The climate change will cause the conversion of the best agricultural lands into the marginal ones in all soil units of the study area due to bioclimatic deficiency for the future scenario (A1). Therefore, a total of 3 860 ha has converted from excellent to good capable agricultural lands.

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