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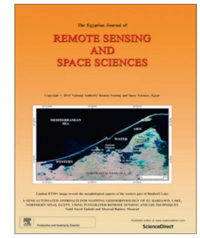

RESEARCH PAPER

Assessment of land suitability and the possibility and performance of a canola (*Brassica napus* L.) – soybean (*Glycine max* L.) rotation in four basins of Golestan province, Iran

Behnam Kamkar [a,*], Mohammad Ali Dorri [b], Jaime A. Teixeira da Silva [c]

[a] *Department of Agronomy, Gorgan University of Agricultural Science and Natural Resources (GUASNR), Faculty of Plant Production, Basij Square, Pardis No. 2, 49189-43464 Gorgan, Iran*
[b] *Agronomy Dept., Gorgan University of Agricultural Sciences and Natural Resources (GUASNR) & Scientific Member of Agricultural Research Center and Natural Resources of Golestan, Basij Square, Pardis No. 2, 49189-43464 Gorgan, Iran*
[c] *P.O. Box 7, Miki-cho post office, Ikenobe 3011-2, Kagawa-ken 761-0799, Japan*

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Abstract A Geographical Information System (GIS)-based plan was used to assess the possibility and performance of a canola (*Brassica napus* L.) – soybean (*Glycine max* L.) rotation in Golestan province, one of the most important agricultural production regions of Iran. For this purpose, all needed raster layers, including climatic (precipitation, temperature), topographic (aspects and slope) and soil-related (texture, pH, EC) layers, were provided by interpolation, surface analysis and other related techniques in GIS. Overlaid layers were used to judge the capacity of agricultural lands to rotate a canola–soybean system in the study area, which included four important basins. Based on defined scenarios and pre-determined ecological requirements of the two studied crops, five suitability classes were detected and mapped. Our results indicate that just 11.82% of total lands are very suitable to rotate soybean after canola while most agricultural lands in the study area fell into the moderate and low suitability classes. The consistency of results adopted from final overlaid maps with real statistics in the study region show that GIS as a systemic approach can play a vital role in saving time and reducing

* Corresponding author. Tel.: +98 171 4427060; fax: +98 171 4427060.
E-mail address: kamkar@gau.ac.ir (B. Kamkar).

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research costs. These results could help policy makers to design proper cropping patterns, particularly rotation systems.

1. Introduction

The rapidly growing world population places considerable pressure on increasingly scarce natural resources, spurring the need to develop more efficient and sustainable agricultural production systems to feed these growing populations. Many variables that influence plant growth and development can be modified by farmers. One of the most important objectives in agriculture is to improve land management and cropping patterns to increase agricultural production with the efficient use of land resources. Many managers use conventional data collection techniques for monitoring crops, estimating yield and selecting crops that are established from ground-based visits and reports. These methods are subjective, very costly and time- and human resource-consuming. Crop selection based on land capabilities has been used in several studies to assess the suitability of land for specific crops in order to determine the optimal cropping system (Rahman and Saha, 2008; Reshmidevi et al., 2009).

Early prediction of the suitability of crops, through selection and extrapolation of the extent to which different crops should be planted, is important for planning and implementing various policy decisions. The potential of land for agricultural use is determined by evaluating the components related to climate, soil and topographical environment and by understanding local biophysical restraints (Grassano et al., 2011).

Agro-climatic and agro-ecological zoning schemes are standard tools for prioritizing agricultural research because they offer relevant and available information about target environments (Corbett, 1996). The most obvious influences of weather on crop yield during the growing season are precipitation and temperature (Giardini et al., 1997). The climatic conditions and soil quality of an area are the most important determinant parameters of land suitability evaluations.

Overlaying different layers or maps can be considered as an effective way to assess the suitability of a crop at a territorial level, as for energy crops (Pellerano et al., 2007; Ghasemi Pirbalouti, 2009).

Maize, rice, wheat, barley, cotton, soybean and canola are the major crops found in the agricultural production systems of Golestan province, Iran. Soybean (*Glycine max* L.; *Fabaceae*) is grown world-wide as an important staple and commercial crop. The area reserved for planting soybean around the world and in Iran is 99,501,101 and 84,084 ha, respectively (FAO/STAT, 2009). Soybean accounted for 56% of production of the main world oilseed crops in 2011 with a total production of 251.5 million tons (ASA, 2012). This crop currently covers more than 50,000 ha of agricultural lands in Golestan province and is ranked as the top soybean-producing area of Iran with about 75% of total soybean production and an average yield of 2480 kg ha^{-1} (Anonymous, 2010a; Jihad-e-Agriculture Ministry, 2010). It is one of the main summer crops in Golestan province with an estimated production of about 209,000 tons in Iran while the harvested land area was about 115,000 ha in 2008 (Anonymous, 2010b).

The suitable temperature for soybean is 15–22 °C at emergence, 20–25 °C at flowering, and 15–22 °C at maturity (Liu et al., 2008). Setiyono et al. (2010) used a location at 190–357 m above sea level to study soybean growth and yield at near-optimal growth conditions. Soybean yield was negatively related to altitude and slope indicating that lower, flatter areas of a field had higher yields (Cox et al., 2003; Kravchenko and Bullock, 2000; McConkey and Ulrich, 1997). The response of soybean to salinity varies and depends on the variety (Katerji et al., 2000), and ranges from sensitive to moderate, while canola (*Brassica napus* L.; *Brassicaceae*) has been categorized as being salt tolerant (Ashraf and McNeilly, 1990). Rostami Hir et al. (2004) reported that soybean cultivars cultivated in Golestan province responded differently to salinity, with 'Gorgan 3' having the lowest yield among 11 cultivars at 6.7 dS m^{-1}. Soybean yield under salt stress was reduced by 20% at 4.0 dS m^{-1} and by 56% at 6.7 dS m^{-1} compared with yield at a low salt concentration (0.8 dS m^{-1}) (Katerji et al., 2003). This may be explained by the salt sensitivity of *Rhizobium* bacteria, which affect the nitrogen supply, by the degree of osmotic adjustment or by prolongation of the flowering period (Katerji et al., 2001).

Canola seed contains both high oil and protein content (Grassano et al., 2011). In Iran, canola is located in areas that receive reliable rainfall and is one of the main winter crops in Golestan province.

Kutcher et al. (2010) reported the negative impacts of high temperatures and low precipitation on canola yield, demonstrating a critical period in which high temperatures (> 30 °C) and low precipitation would lead to a loss in yield. Prior to flowering, the flowering period and the pod developmental stage are critical periods, i.e. most sensitive to environmental fluctuations and extremes (Gan et al., 2004). Nuttal et al. (1992) reported that a 3 °C (21–24 °C) rise in maximum daily temperature during flowering resulted in a decline of 430 kg ha^{-1} in canola seed yield. Gan et al. (2004) found that the seed yield of canola decreased by 15% when high temperature stress was applied before flowering but that yield reduction was 58% when heat stress was delayed to the flowering period and further to 77% when the stress was delayed to the pod developmental stage.

In Iran, the average cultivation area in 2010–2011 was 42,000 and 18,000 ha for soybean and canola, respectively (Jihade Agriculture province Office, unpublished data). Ghasemi Pirbalouti et al. (2008) reported that the cultivation area of canola in Iran exceeded 100,000 ha. Chaharmahal va Bakhtyari (30°42′–33°37′ N and 49°56′–51°57′ E), a traditional canola-producing province with an average yield of about 2035 kg ha^{-1}, is located in a region of Iran with an annual rainfall of 650 mm and average annual temperature of 13 °C (Rahimi et al., 2011).

The selection of a suitable grain crop rotation within this province would increase the yield stability of each crop individually and overall agricultural yield. Soybean is considered to be the next best suitable alternative after canola. Myers

(2002) reported that soybean has no allelopathic effect on soybean. Crop rotation has been evaluated to a limited extent at a few sites in Golestan province in the past but there has never been a systematic evaluation of resources that takes into consideration the requirements for a rotation crop. Moreover, land suitability as the first step of a land use plan has not yet been assessed. The process of land suitability classification involves the evaluation and grouping of specific areas of land in terms of their suitability for a defined use. The definition of land suitability is the suitability of a given type of land to support a defined land use, either in its current state or after improvements (Gong et al., 2012). The evaluation of land suitability is the process of appraising and grouping specific areas of land to assess their suitability for these defined uses (Liu et al., 2006). In addition, applying the results of land suitability is necessary because of the potential to improve resource management, to achieve optimum productivity of the land and to ensure environmental sustainability. Abbaspour et al. (2011), with assessing the relative importance of factors to analyze the suitability of land for agriculture in Golestan province using the analytical hierarchy process (AHP) method, indicated that soil capacity had a relative weight of 0.284 and was the most important factor while slope and precipitation were the second and third most important factors.

Those who use Geographical Information System (GIS) in agriculture recognize that the potential application of GIS in agriculture is large. However, the GIS user community in production agriculture is small compared to other business sectors. There is a lack of formal opportunities to share applications and innovations of GIS specifically focused on agriculture (Pierce and Clay, 2007). To support and advance the use of GIS in agriculture, our intent was to perform an integrative method to establish a canola–soybean rotation map.

Traditional methods based on manual procedures become unwieldy to implement or even inappropriate. Indeed, the implementation of these procedures requires a lot of time because of the thesaurus of data and may be subjected to errors (human and/or graphical). Current approaches, based on GIS, spatial analysis and multicriteria analysis are available and are able to assist in management and decision-making (Mendas et al., 2007).

The main objective of land evaluation is the prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize socioeconomic and environmental costs (De La Rosa, 2000; Neamatollahi et al., 2002). The Geographical Information System (GIS) offers a flexible and powerful tool as it can combine large volumes of different kinds of data into new datasets and display these new datasets in the form of informative and accessible thematic maps (Foote and Lynch, 1996; Marble et al., 1984).

The aim of this study was to perform land suitability assessments for canola and soybean cultivation in four important basins of Golestan province, and to investigate the possibility of implementing a canola–soybean rotation. In this way, we used GIS and a comprehensive data set on both crops ecological requirements, agroclimicat, topographic and soil data.

2. Materials and methods

In this study, four basins located in Golestan province in northern Iran were selected. The basins, extending from the west to the east, are Gharesoo (1675.62 km^2), Gharnabad (344.1 km^2), Mohammadabad (875.86 km^2) and Zaringol (1153.33 km^2) (Fig. 1). These areas extend from 36°35′ N to 37°14′ N and from 54°2′ E to 55°11′ E. The study area covers approximately 404,892 with 214,140.16 ha (Natural Resources and Watershed Office data) currently in agricultural use (Fig. 1). Using 1: 25,000 maps of the national cartographic center of Iran, we created a 20 m digital elevation model (DEM) with a topo-to-raster function.

Temperature and precipitation data were collected and recorded at the stations located within the study area and the surrounding zone in a period ranging from 5 to over 30 years. This data was interpolated to calculate meteorological data for all the map points. Spatial interpolation is the procedure of estimating the value of quantities at unsampled sites within an area covered by existing observations and geostatistical interpolation techniques utilize the statistical properties of the measured points (Apaydin, 2004).

Climatic variables, including minimum and maximum temperatures as well as precipitation, were estimated based on long-term statistics of synoptic stations by using multiple regressions. Climate data are often strongly related to topographic and geographic variables, which can be integrated using multiple regression techniques (Agnew and Palutikof, 2000; Ninyerola et al., 2000). For this purpose, at first, the central points of each network were extracted from the DEM layer. Using coordinates of these points and regression relations, multiple independent variable models were extracted to provide a climatic variables raster. Each variable layer was converted to raster data by applying a topo-to-raster function. These layers were provided for each month in a 12-month period from December to November and then final layers were prepared for the growing season of each given crop by cell statistics functions.

Electrical conductivity (EC), soil texture and pH data were collected from a regional study (unpublished data). Moreover, data on ecological requirements of soybean and canola were collected from different literature sources (Table 1).

The optimum growth conditions in related scenarios were defined for each crop based on data in Table 1. Then, rasters of climatic factors (maximum, minimum and average temperature, rainfall), soil characteristics (EC, pH and texture) and topographic features (slope and elevation) were reclassified by the natural breaks (syn. Jenks) method, which has been used in various scientific research fields (Hall et al., 2008; Mennis and Liu, 2005; Osaragi, 2002). Thereafter, reclassified layers were overlaid by a raster calculator. These overlaid layers were used to assess land suitability for these crops. Based on the above-mentioned lands, the studied basins were categorized into five groups: very suitable (S1), suitable (S2), moderately suitable (S3), poorly suitable (S4) and unsuitable (S5). In other words, the five groups were classified qualitatively as very good (S1) to poor (S5). According to the data in Table 1, optimum conditions were determined for each crop, and land suitability was conducted using these optimized conditions.

3. Results and discussion

This study was conducted to assess the suitability of land in Golestan province, Iran for a canola–soybean rotation. Our results, based on long-term weather data, showed that both

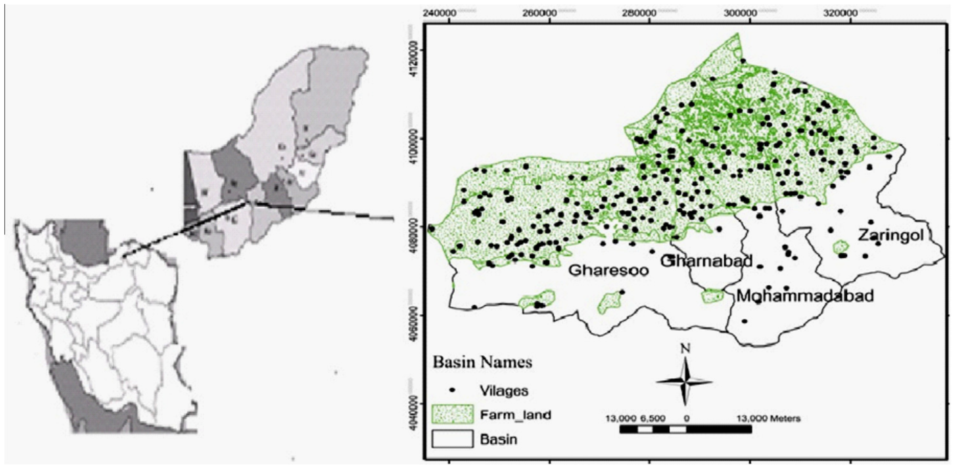

Figure 1 Study basins and farm lands.

Table 1 Crop requirements of canola and soybean collected from different literature sources.

		Canola	References	Soybean	References
Temp. (°C)	Min	4	Goudriaan and Van Laar (1994), De Mastro et al. (1998), Morrison and Stewart (2002)	10	Kumar et al. (2008a,b), Seddigh and Jolliff (1984)
	Opt	17		24	
	Max	30		36	
Salinity threshold (dS m^{-1}) (50% yield reduction)		11	Francois (1994)	5	Abel and MacKenzie (1964), Bernstein and Ogata (1966)
pH		6–7	Boyles at al. (2009)	6.5–7.5	Cherney at al. (2008)
Soil texture		Wide soil	Boyles at al. (2009)	Wide soil	Kandel (2010)
Rainfall (mm)		325–700	http://www.ogtr.gov.au (2008)	Irrigation is necessary	Summer rainfall is insufficient
Elevation (m)		< 800	Weiss (1983)	300	Weiss (1983)
Slope (%)		< 8	Lee and Glickman (2008)	< 5	Bagli et al, (2003)

canola and soybean are not faced with limiting temperatures during the growing season. The minimum and maximum temperature layers during the growing season indicate that mean temperature for the growing season was in a suitable range for both crops. In the study area, daily temperatures during winter often ranged from a minimum of about 4 °C to a maximum of 18 °C allowing for the production of canola in more agricultural lands. Mean daily temperatures during the

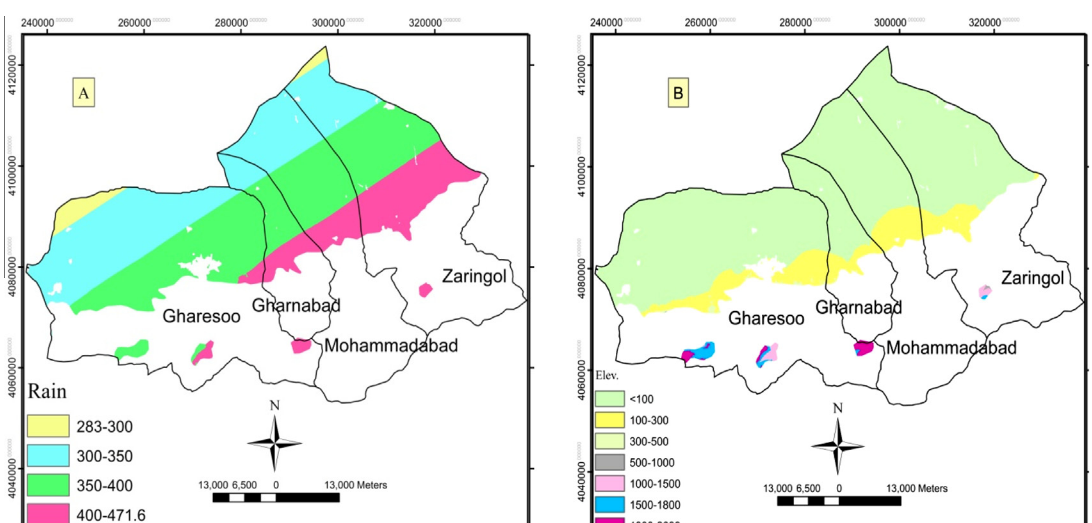

Figure 2 Reclassified maps: rainfall (a) and elevation (b) for agricultural lands in the four studied basins.

soybean growing season from the sowing date in late June until harvesting time in mid- to late-October ranged from a minimum of more than 10 °C to a maximum of 31 °C. Therefore, minimum and maximum temperatures in winter for canola and in summer for soybean were not limiting factors in the four studied basins. Heat stress during flowering of canola can prematurely end flowering, resulting in limited seed set.

Soil pH range was between 7.5 and 7.8 in all study areas and was thus not considered to be a limiting factor. Various layers, including rain, elevation, slope and EC (Figs. 2a, 2b, 3a, 3b, 3c, and 3d), were overlaid to create land units of unique characteristics. Different components, which were separately multiplied together, can have extremely limiting effects on the land suitability of a crop.

Liebig's Law, i.e., the minimum law (Rubio et al., 2003) can be used to describe some results in more detail. Thus, if precipitation for canola production was insufficient as an important factor, then land suitability was classified as very unsuitable, regardless of the suitability of the other components. Identifying agro-zoning scenarios based on collected data (Table 1) for both canola and soybean, lands were categorized into five groups: very suitable (S1), suitable (S2), moderately suitable (S3), poorly suitable (S4) and unsuitable (S5).

Maps for canola cultivation revealed that 53,466 ha (24.97%) of agricultural lands have a different potential for canola production (Table 2). This crop covers, at present, 22,000 ha of agricultural land of Golestan province with an average yield of 1580 kg ha^{-1} (Anonymous, 2010a). For canola, based on Jenk's method, the S1 class was located in the area of the study basins where the lowest limit was caused by EC and precipitation.

The overlaid maps (Fig. 4a) for climatic variables (maximum and minimum daily average temperature and summed precipitation in the growing season) indicate that 0.62% (332.76 ha), 16.27% (8699.36 ha), 65.94% (35257.52 ha), 12.95% (6922.84 ha) and 4.22% (2253.84 ha) of lands in Golestan province (Table 2) are located in S1, S2, S3, S4 and S5 suitability classes, respectively for canola cultivation under both rainfed

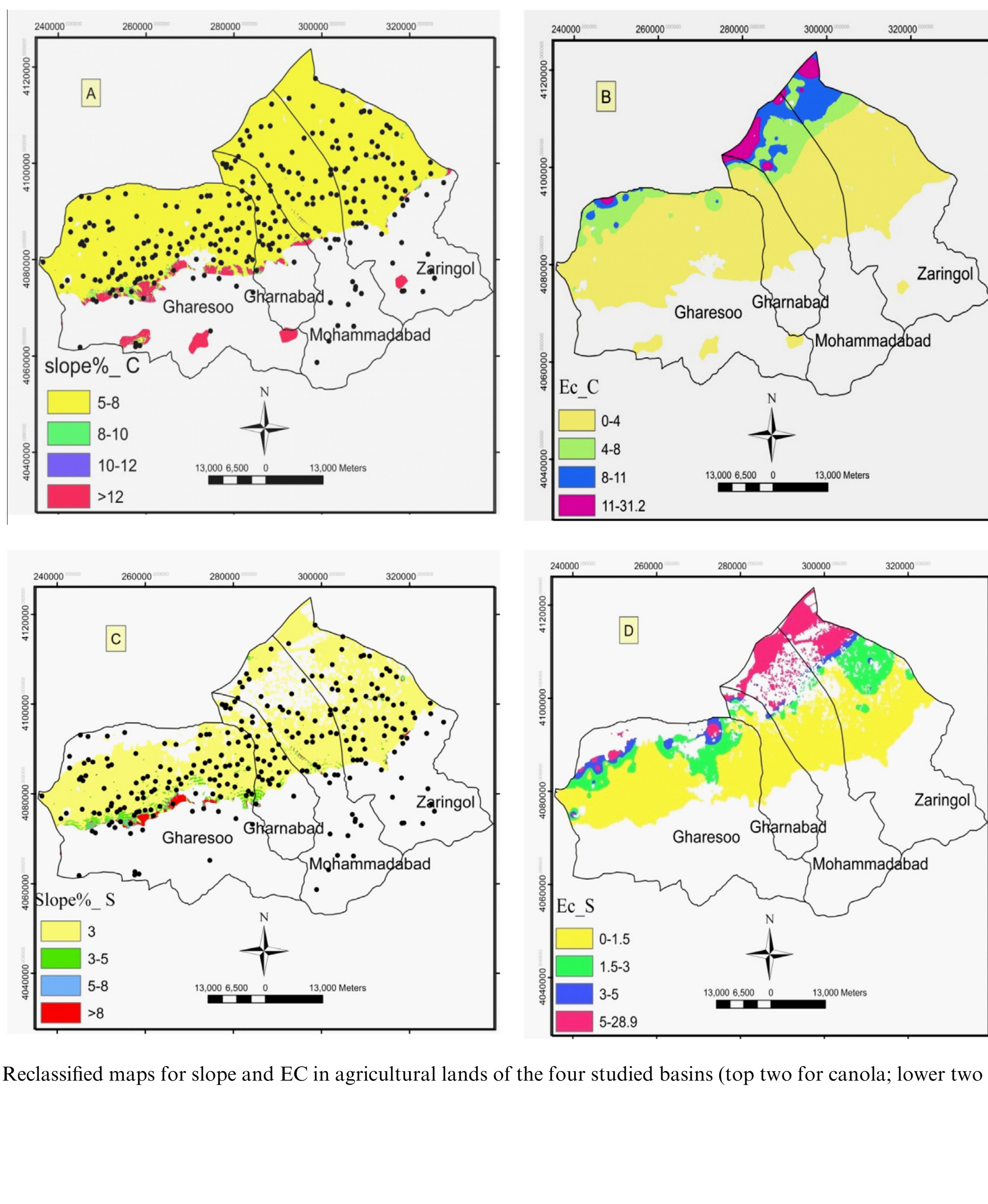

Figure 3 Reclassified maps for slope and EC in agricultural lands of the four studied basins (top two for canola; lower two for soybean).

Table 2 Related area to different suitability classes for soybean and canola cultivation in the study area.

Suitability	Canola		Soybean	
	Area (ha)	% Out of total	Area (ha)	% Out of total
Very suitable	332.76	0.62	4448.88	11.59
Suitable	8699.36	16.27	16160.28	42.1
Moderately suitable	35257.52	65.94	16779.08	43.71
Poorly suitable	6922.84	12.95	970.4	2.52
Very poorly suitable	2253.84	4.22	29.4	0.08
Total area	53466.32	100	38388.04	100

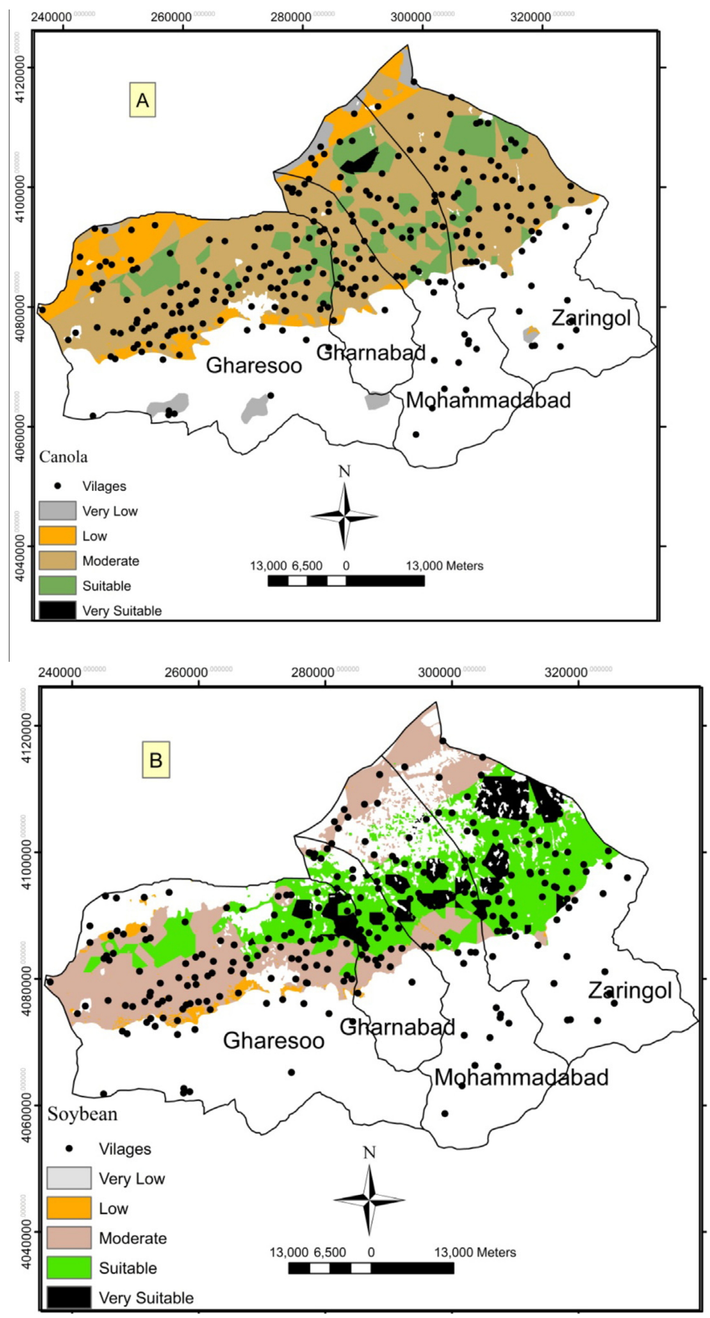

Figure 4 Land suitability map of canola (a) and soybean cultivation (b) in the study area.

and irrigated conditions. Canola is reasonably widely adapted and performed well in many areas under variable temperatures. This result shows that in these basins, there is the possibility of increasing the canola production area up to 53,466 ha.

Considering the final map (Fig. 4a), the best areas for cultivating canola are located in Zaringol and Mohammadabad basins. Precipitation, an important factor, is lower than optimum or is even insufficient in some areas (Fig. 2a). Based on given scenarios, more than half of the land for canola is moderately suitable (S3).There are some main factors, such as salinity and low rainfall, which limit both suitable lands and actual seed yield. Comparing average seed yield with other production areas shows that average yield in Golestan province is lower than Chaharmahal va Bakhtyari (1580 vs 2035 kg ha^{-1}). Our results indicate that the study area has an annual rainfall of 283–471 mm. As mentioned above, temperatures fell within the optimum range in the study area, thus it seems as if high annual rainfall (at least 179 mm) is an effective factor and may be areas on for the higher average seed yield in Chaharmahal va Bakhtyari, relative to Golestan province. Although canola is mostly cultivated as a rainfed crop in Golestan province, supplemental irrigation is expected to be necessary to increase yield and to decrease the gap to achieving maximum expected yield.

Maps were also overlaid to detect different suitability classes for soybean cultivation. The created map showed that 11.59% (4448.88 ha), 42.21% (16160.28 ha), 43.71% (16779.08 ha), 2.52% (970.24 ha) and 0.08% (29.4 ha) of lands (Table 2) are located in S1, S2, S3, S4 and S5 suitability classes, respectively for cultivation under irrigation (Fig. 4b). Irrigation also is an important factor affecting soybean growth and yield (Aminifar et al., 2012).

Soybean cultivation area and production in Golestan province are the highest among other soybean-producing regions in Iran. Based on current data (Anonymous, 2010a), the main areas of soybean cultivation with 36,000 ha are located in the studied areas. It is close to values mentioned in Table 2 for soybean cultivation areas (38,388.04 ha).Although more than 90% of soybean cultivable areas are found in the study area, an important result of this study is to define land suitability classes for soybean cultivation which can help decision makers to plan optimal management recommendations for soybean cultivation in the future

The land suitability results for soybean showed that less than 2.5% of total lands are in a poor suitable class (i.e., S5) in the four studied basins. Only 0.62% and 11.59% of total agricultural lands were classified as being very suitable for canola and soybean production, respectively.

Soybean is classified as moderately tolerant to salinity with a threshold of 5 dS m^{-1}, beyond which growth is markedly reduced (Maas and Hoffman, 1977). Nevertheless, other authors have suggested lower threshold values, around 2 dS m^{-1} (Katerji et al., 2000). These results confirmed that EC is one of the most limiting factors for soybean cultivation, a possibility which should be considered in Golestan province. Most lands classified as being highly suitable for soybean cultivation are located in Mohammadabad and Zaringol basins, while moderate and suitable classes are located in Gharesoo (Fig. 4b).

After determining the suitability of land for canola and soybean, agricultural lands for rotating soybean as a double crop were determined on a new map (Fig. 5). Double cropping, possible in these areas as a cropping system, has several advantages. Soybean cultivation after canola in some areas of Golestan province is already conventional. Production practices, equipment needs, production costs and the growing season for canola are quite similar to wheat (Murdock et al., 2013). Canola–soybean offers a profitable opportunity to diversify crops, and to break disease and pest cycles established by using current crops. Winter canola (*Brassica napus* L.) is an alternative winter grain crop that provides high quality edible oil for various uses and defatted meal for livestock and poultry

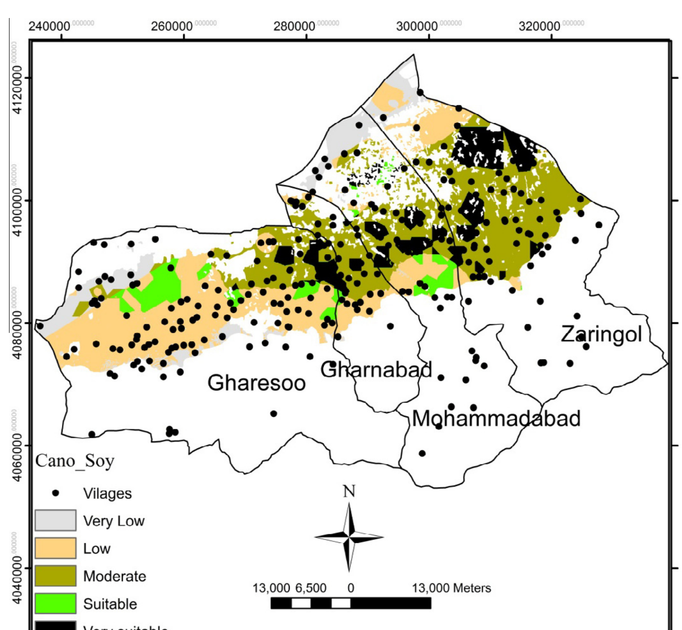

Figure 5 Land suitability map for canola–soybean rotation.

Table 3 Land suitability for canola–soybean rotation.

Suitability	Canola–soybean	
	Area (ha)	% Out of total
Very suitable	4536.8	11.82
Suitable	2475.2	6.45
Moderately suitable	13882.76	36.17
Poorly suitable	13350.12	34.78
Very poorly suitable	4139.32	10.78
Total area	38384.2	100

(Öztürk, 2010). Canola generally matures earlier than wheat and this can allow earlier planting of the next crop (Murdock et al., 2013).

Areas with low and very low suitability for canola and soybean are located in north and south of the study area (Fig. 4a and b). This result is based on the soil EC layer because the EC of soils in some parts of areas, particularly in the north of basins [11–31.2 dS m^{-1} (Fig. 3c) and 5–28 dS m^{-1} (Fig. 3d)], was higher than the salinity tolerance threshold of canola (11 dS m^{-1}) and soybean (5 dS m^{-1}) (Table 1). A rotation map (Fig. 5) was created by overlaying layers that show the best conditions. Soybean is cultivated in Golestan province under irrigation, so dry lands were excluded.

Lands with an EC 5 dS m^{-1}, a slope $<5\%$, an elevation <300 m, and a minimum temperature of >4 °C and >10 °C in winter and summer, respectively are considered to be highly suitable lands (Fig. 5). The land suitability map for canola–soybean cultivation in rotation (Fig. 5) showed that 11.82% (4536.8 ha), 6.45% (2475.2 ha), 36.17% (13882.76 ha), 34.78% (13350.12 ha) and 10.78% (4139.32 ha) of lands (Table 3) are located in S1, S2, S3, S4 and S5 suitability classes, respectively (Table 3). These results indicate that very suitable areas for rotating canola and soybean are located in the east of the study area (Zaringol basin), totaling 2308.31 ha (equal to 50.89% of the S1 area). Land classified as S5 has a very low capacity of sustaining the canola–soybean rotation since soil salinity and low rainfall are the key limiting factors in these areas. Thus, to be able to utilize these areas, soil amendment and use of integrated irrigation is suggested.

Although soybean as a major summer crop is grown as an irrigated crop in Golestan province, soil EC is a very important limiting factor that should be considered for planting areas. Areas with an EC <1.5 dS m^{-1} (as non-saline soils) were estimated in 67% of irrigated areas (154,249.12 ha) and lands with an EC <4 dS m^{-1} were detected in 77.7% of the total of dry land and irrigated areas (214,140.16 ha).

A 50% reduction in yield occurred at 5 and 11 dS m^{-1} for soybean and canola, respectively (Table 1), but the best growth for soybean occurred in non-saline soils. Therefore, very suitable lands for rotation with canola were selected based on two main factors: EC $\leqslant 2$ dS m^{-1} (Hall et al., 2008) and irrigated lands. The lands which are suitable for soybean cultivation based on EC are also surely suitable for the cultivation of canola (Fig. 5). These areas amount to 34,244 ha.

The final maps showed that less than 3% of agricultural lands (29.4 ha) are located in an unsuitable class for soybean. This result indicates that there are large tracts of land available for soybean cropping, in agreement with an anonymous report (Anonymous, 2010a) for Golestan province.

4. Conclusion

Results clearly reveal that lands which are located in the east of the four studied basins in Golestan province are located in a very suitable class for soybean and in a suitable class for canola cultivation, when rotated. This study aimed to classify lands with different degrees of suitability as an index to help decision makers and farmers, especially where crop selection is considered to be an important component of management. Determination of lands as being highly suitable for soybean and suitable for canola cropping and their rotation will be lead to the optimization of these important rotation systems to achieve higher yield. Our results also confirmed the ability of GIS as a tool to rapidly assess the ability to cultivate agro-ecosystems, with such systematic approaches saving time and reducing costs, which would be useful for policy makers and growers.

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