Anadolu Tarım Bilim. Derg., 2010,25(S-3):184-191
Anadolu J. Agric. Sci., 2010,25(S-3):184-191

Research
Araştırma

APPLICATION OF GIS MODEL IN PHYSICAL LAND EVALUATION SUITABILITY FOR RICE CULTIVATION

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Abstract: The objective of this study was to establish spatial model in land evaluation for rice cultivation using GIS in Bafra Plain found in the Kızılırmak Delta and located in the central Black Sea region of Turkey. The study area covers about 4823.7 ha. A land unit resulted from the overlay process of the selected theme layers has unique information of land qualities for which the suitability is based on. The selected theme layers of rice include topographic factor (slope), soil physical factors (soil depth, soil texture, drainage, stoniness, hydraulic conductivity) and soil chemical factors (pH, electrical conductivity, $CaCO_3$ and soil fertility). These theme layers were collected from existing information. Spatial information of soil physical and soil chemical factors were formulated using soil map database. Slope layer of the study area was prepared from DEM. Each land characteristics is also considered as a thematic layer in the GIS. In addition, each of land quality layers with associated attribute data is digitally encoded in a GIS database. After combination of these layers, a resultant map was produced. Land suitability rating model applied to the resultant polygonal layer provided the suitability classes for field crops. Results showed that 79% of the study area is highly and moderately suitable for field crops, whereas 21% of the study area is low and non suitable for rice cultivation due to soil and land conditions. The resultant suitability classes were also checked with field experiment study. 12 rice species were used in experiments. ANOVA was done for grain yield and $LSD_{0.05}$ test was implemented for comparison of mean values in the TARIST statistics package. According to ANOVA results, it was found significantly positive relationship between land suitability classes and grain yield values. The grain yield values were affected at level of $P<0.001$ by land suitability class. In general, the highest grain yield was obtained from rice plots located in S1 class, S2 and S3 classes followed it as well. As for $LSD_{0.05}$ test results, the highest yield values were determined Halil Bey (789.9^{a}), Osmancık-97 (760.5^{ab}) and Durağan (751.0^{b}) in 12 rice species for S1 class while, the highest yield values were found Osmancık-97 (696.1^{a}), Şumnu (688.8^{ab}) and Neğiş (654.1^{bc}) in 12 rice species for S3 class.
Key Words: Land suitability, Soil map, GIS, Rice cultivation

1. INTRODUCTION

Rice is not only the staple food for nearly half of the World's population relying on rice as the major daily source of calories and protein, but also a key source of employment and income for the rural people (FAO, 2003). It ranks as second the main agricultural production in most of Asian countries. Rice is grown in 156 million hectares and the production is 660 million tons in the World (Gençtan, 2009). Rice is also an important cereal crop for Turkey. Rice is grown in every part of Turkey, however, Marmara especially Europe part of Marmara (Thrace) and Black Sea region are the main rice production areas respectively. Turkey has approximately 27.5 million ha total cultivable area only, very small part of it (about 80,000 ha) has been cultivated with rice and total production is about 156.000 tons (Gençtan, 2009). Although most regions in Turkey ecologically are suitable for rice cultivation, this area and rice production in Turkey are not enough for domestic consumption (Sürek, 1998). Rice imports have therefore increased in the last decades. To cope with this problem, it should be increased cultivated rice area.Efficient management of natural resources is essential for ensuring food supplies and sustainability in agricultural development. The task of meeting the demands of man without affecting the ecological assets for the future generations is being given top priority by both scientists and planners. It is indicated that there is an urgent need to match the land resource and the land use in the most possible and logical way to continue sustainable production and to meet the needs of society while conserving fragile ecosystem FAO (1993). The management and analysis of large volumes of spatial data requires computer based systems called Geographical Information System (GIS) which can be used for solving complex geographical and hydrological problems (Garg, 1991). Geographical information system is defined as a system of computer hardware and software designed to allow users to collect, manage, analyse, and retrieve large volumes of spatially referenced data collected from variety of sources (Aronoff, 1991). However, traditional management ability has generally been limited for two reasons: the difficulty in acquiring useful information over vast areas and the lack of a means for effective process and analyse the acquired data (Champbell, 1987). Due to many factors that are associated with each feature under study, analysis, manipulation, and using manual methods cost too much. Besides, they consume too much time or practically impossible. Today advanced computer programs including decision support systems (Geographic Information System and Remote Sensing) contribute to the speed and efficiency of the overall planning process and allow access to large amounts of useful information quickly. Especially during the last decade, GIS and RS have received much attention in application related to resources at large spatial scales (Green, 1995; Hinton, 1996). Therefore, GIS is a powerful tool for management and analysis of data required for any land developmental activity. Therefore, systematic approach to produce information on the suitability is needed.Perera et al. (1993) studied that GIS based research has been carried out to extract new land for rice cultivation in south Sri Lanka with special concern on environmental conservation. The locations of the worth considering lands and impractical lands for paddy cultivation were analyzed and merged with the GIS data base by a specially arranged point system. According to their study, more than 72% of the selected land was classified as highly suitable or suitable for rice cultivation. In addition, Mongkolsawat and others (2002) who studied to establish spatial model in land evaluation for rice using GIS in the lower Namphong watershed located in Northeast Thailand determined the highly suitable land cover an area of about 208.3 km^2 and some 17.7 % of the watershed is unsuitable area for rice which corresponds to the slope land. The resultant suitability class were checked against the rice yield which collected by the Department of Agriculture Extension and they found that it was to be satisfactory.The main objectives of this study are to identify the most suitable areas for rice cultivation while conserving the environment and to establish spatial model in land evaluation for rice cultivation which is based on GIS and digital mapping.

2. MATERIALS AND METHODS

2.1. Description of The Study Areas

This study was carried out in the Bafra Plain found in the Kızılırmak Delta and located in the central Black Sea region of Turkey (Figure 1). The study area (around the Doğanca village) is far 10 km from north of the Samsun-Bafra district (4615-4615 km N- 243-250 km UTM), It covers 4823.7 ha and its lies at an elevation from sea level 1-3 m. The current climate in the region is semi-humid. The summers are warmer than winters (the average temperature in July is 22.2 and in January is 6.9 ^{o}C). The mean annual temperature, rainfall and evaporation are 13.6 ºC, 764.3 mm and 726.7 mm respectively. According to Soil Taxonomy (1999), the study site has mesic soil temperature regime and ustic moisture regime. These areas are mainly flat and slightly sloped (0-2 %). The majority of soils were Vertisol, Inceptisol and Entisol in Soil Taxonomy (1999). Top soil texture is heavy (31-60 % clay), while sub soil texture is different due to alluvial deposit in the study area. Soil organic matter content ranges from 1.70 % to 5.92. EC and pH values of soils are changing 0.61-2.79 dS m^{-1} and 7.28- 8.01. The study area has been under intensive agricultural activities. Rice, maize, pepper, watermelon, cucumber and tomato with sprinkler and furrow irrigations in the summer, and cabbage and leek in the winter have been produced in the study area.

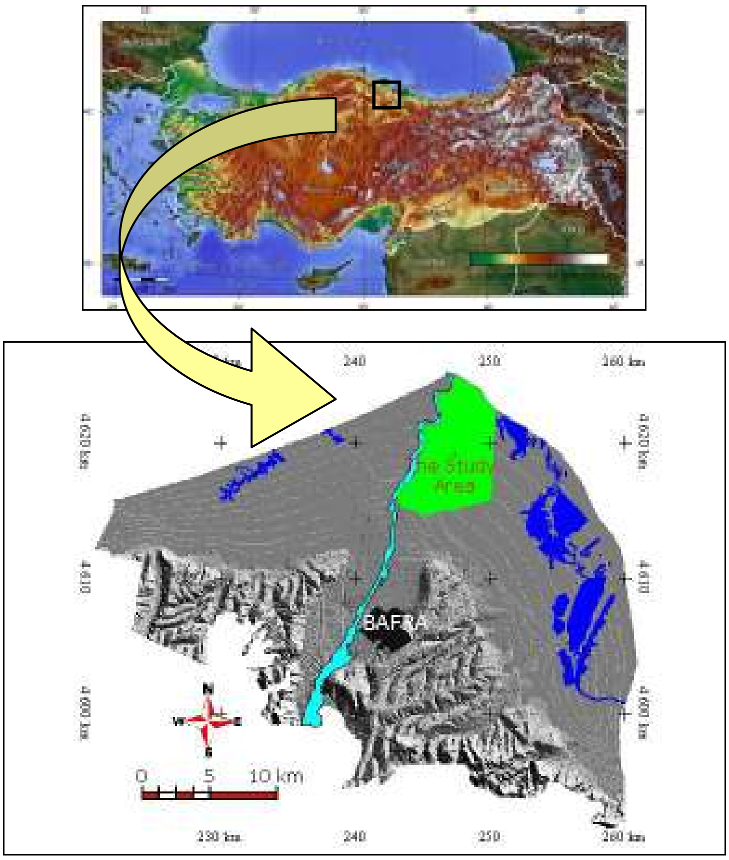

Figure 1. Location of the study area

2.2. Methods

Land utilization types were described by a set of land-use requirements or land quality parameters, which are the land conditions necessary for successful farming, while land map units were described by a set of land characteristics, which are land attributes that influence their suitability for given land utilization types (Van Diepen et al., 1991). Land utilization type is rice in this study. Land-use requirement of rice, in terms of topographic and soil physico-chemical criteria were reviewed from FAO (1983 and 1985), Sys et al (1993), Mongkolsawat et al. (2002), Bunting (1981), Yamada et al. (1995), Sönmez (2003) ve Özcan (2004). These criteria are commonly implemented in physical land evaluation using Table 1.

In order to develop a set of themes for evaluation and ultimately to produce a suitability map for rice, soil and topographic data were taken from digital soil map of the study area. In addition, results obtained from experimental reports and regional experiences were adopted to identify land quality as related to rice ecological conditions. The land qualities used for this evaluation include two main indexes; Nutrient Availability Index (NAI) and Soil Quality Index (SQI). NAI were calculated using the following formulas

$$NAI = N \times P \times K \times Zn$$

Table 1. Factor rating of land quality parameters for rice

Land quality parameters			Factor rating			
	Diagnostic Factor	Unit	1.0	0.8	0.5	0.2
			> □0.60	0.40-0.60	0.10-0.40	< 0.10
I. Nutrient Availability Index (NAI)	NAI= N*P*K*Zn					
	N P K Zn	% ppm ppm ppm	>0.2 >25 >60 >0.7	0.1-0.2 10-25 30-60 0.7-0.5	<0.1 <10 <30 <0.5	- - - -
II. Soil Quality Index (SQI)	SQI = R*T*D*F*Y*P*G* S*K*H					
Derange (R)		-	Very Poor	Poor	Moderately good	Good/excessive
Texture (T)		%	CL, SiCL, SiL, C, SC	L, SCL, SiC	Si,SL, fSL	G, S, LS
Depth (D)		cm	> 50	25-50	15-25	< 15
Topography (F)	Landform and slope	-	Flood plain or 0-2%	Low terrace or 2-4%	Middle terrace or 4-6%	High terrace/ mountain or >6%
Surface Stoniness (Y)	> 2 mm	%	< 20	20-35	35-55	> 55
Hard Pan (P)		cm	> 90	90-50	50-20	< 20
Hydraulic conductivity (G)		cm/h	< 0.5	0.5-2.0	2.0-6.25	> 6.25
Salinity hazard (S) or ESP		dS/m (%)	0-3.1 10	3.2-4 10-20	4.1-5 > 20	> 5.1 > 20
Lime (K)		%	0-5	5-15	15-20	> 20
Soil reaction (H)	pH	-	5.5-7.3	7.4-7.8 5.1-5.5	7.9-8.4 4.0-5.0	> 8.4 < 4.0

Second formulation is SQI given as follow;

$$SQI = R*T*D*F*Y*P*G*S*K*H$$

Spatial information on each diagnostic characteristic of NAI and SQI was obtained from land mapping units. Each of land characteristics or factors with associated attributed data was digitally encoded in a GIS database to eventually form two thematic layers. The diagnostic properties of each thematic layer were assigned values of factor rating an identified in Table 1. The evaluation model is defined using the value of factor rating as follows;

$$SI = NAI * SQI$$

Where; SI: Suitability Index, NAI: Nutrient Availability Index, and SQI: Soil Quality Index

These two layers were then spatially overlaid to generate a land suitability map. Application of the model to the resultant layer yields a suitability map with four classes according to the resultant values proposed in Table 2.

Schematic chart of the spatial overlay showing the land characteristics and model is illustrated in Figure 2.

2.3. Statistical Analysis

To assess the reliability of the methodology developed, the suitability classes were checked against the rice yield. For this purpose, statistical analyses were performed by using TARIST (1994) statistics package. ANOVA and $LSD_{0.05}$ were done for grain yield values. Field experiment was settled in each suitability class according to randomized block design with three replicates. 12 rice types (Şumnu, Osmancık-97, Gönen, Beşer, Durağan, Halilbey, 7721, Karadeniz, Kızılırmak, Koral, Neğiş and Aromatik-I) were planted in each block.

Table 2. Suitability evaluation of rice

Definition	Suitability Class	Index Value
Highly Suitable	S1	1.00-0.250
Moderate Suitable	S2	0.250-0.100
Marginally Suitable	S3	0.100-0.025
Unsuitable	N	< 0.025

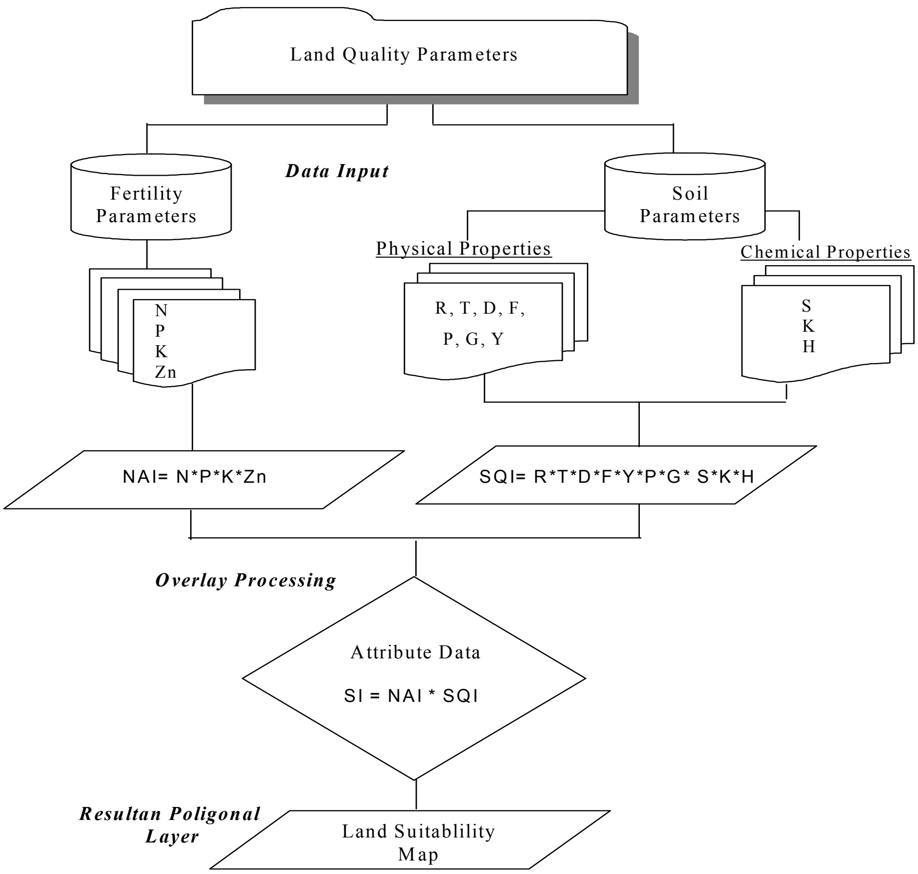

Figure 2. Schematic chart of GIS application to land suitability for rice

3. RESULTS AND DISCUSSION

Land mapping units are adopted as a basis for physical land evaluation in this study. These units are based on combinations of depth, drainage, texture, hydraulic conductivity, surface stoniness, had pan, pH, salinity hazard and lime content There are 20 soil mapping units which are identified in soil map. The description and extent of land mapping units are shown in Figure 3.

Land suitability classification involves the comparison of the land qualities of a land mapping unit or the values of the diagnostic factors for a land mapping unit with the requirements of a land utilization type (expressed in terms of factor ratings). This comparison is part of matching process. This partial suitability for separate land qualities must be combined to come the overall suitability of the land mapping unit for land utilization type (rice). The suitability map resulting from the spatial overlay of factors in the study area is presented in Figure 4. The area of suitability evolution is shown in Table 3. The study provides an approach to identify parametric values in modeling the land suitability for rice. The theme layers to be input in the modeling are assigned the rating value as attribute data. Overall insight into the factors affecting the suitability of land can be provided spatially and quantitatively. The result indicated that the highly and moderately suitable land cover an area of about 3811.6 ha (79 %). 10.8 % of the study area is unsuitable area for rice which corresponds to soil physical and chemical properties.

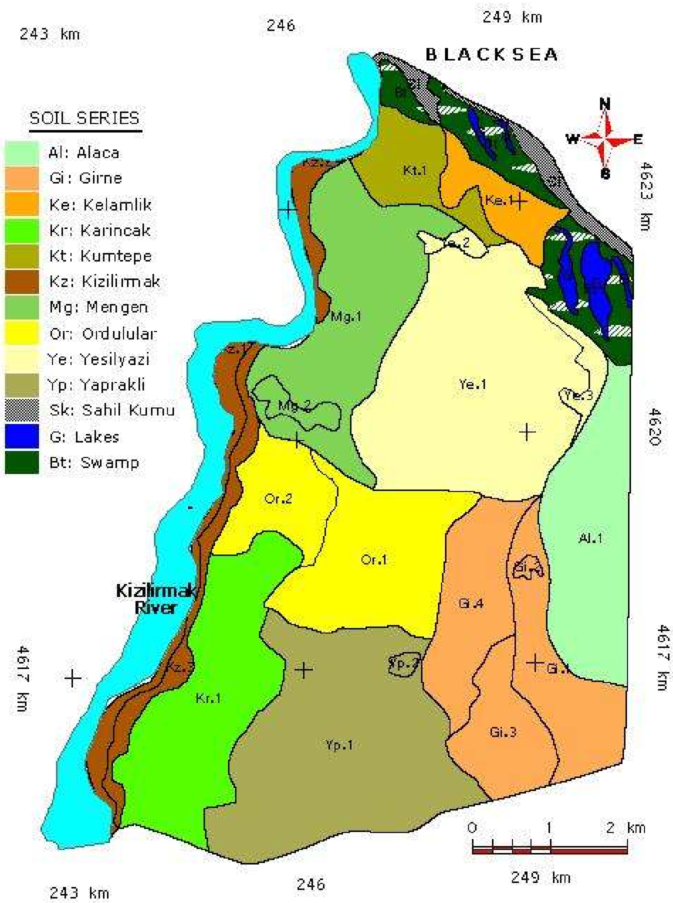

Figure 3. Soil map and land mapping units of the study area

Table 3. Distribution of land suitability class of the study area

Suitability Class	Area (ha)	Ratio (%)
S1: Highly Suitable	2039,2	42,3
S2: Moderate Suitable	1772,4	36,7
S3: Marginally Suitable	492,9	10,2
N: Unsuitable	519,2	10,8
Total	4823,7	100,0

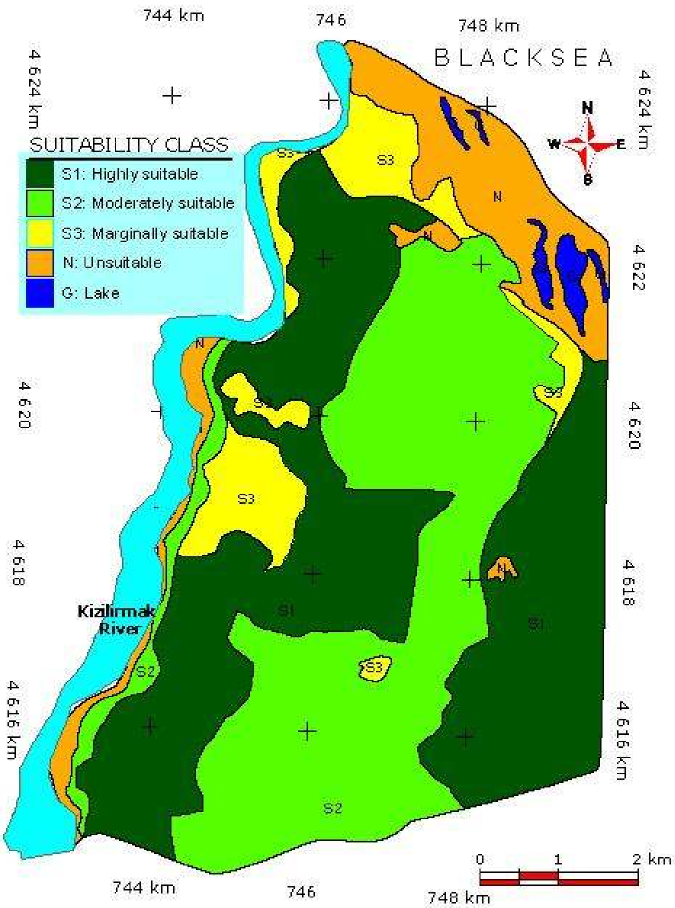

Figure 4. Land suitability map of the study are

To assess the reliability of the methodology developed, the suitability classes were checked against the rice yield. For this purpose, statistical analyses were performed by using TARIST (1994) statistics package. ANOVA and $LSD_{0.05}$ were done for grain yield values. Field experiment was settled in each suitability class according to randomized block design with three replicates. 12 rice species (Şumnu, Osmancık-97, Gönen, Beşer, Durağan, Halilbey, 7721, Karadeniz, Kızılırmak, Koral, Neğiş and Aromatik-I) were planted in each block. Experimental areas were selected according to land suitability classes. In this study, we found that grain yields of all species were affected from location of field experiment (Figure 5). Mean grain yield of the S1, S2 and S3 locations were found at 722.2, 593.9 and 563.3 kg da^{-1}, respectively. There is a discrepancy of 158.9 kg ha^{-1} between S1 and S3 classes. The highest grain yield value of 789.9 kg da^{-1} was obtained for Halil Bey in S1 location. The lowest grain yield value of 432.0 kg da^{-1} was determined for Koral in S3 location (Table 4). ANOVA results indicated that grain yield values were significantly affected by the land suitability class (P<0.001). The effect of each land suitability class was also different for different species. Details on the $LSD_{0.05}$ comparison test were given in Table 4. For the S1 class, the ranking of rice species increasing grain yield was found as Halilbey>Osmancık-97>Durağan> Şumnu> 7721> Kızılırmak>Karadeniz>Gönen>Koral>Neğiş>Aromatik-I>Beşer. Similarly, for S2 and S3, the ranking of rice species increasing grain yield Şumnu > Osmancık- 97 > Gönen > Beşer > Durağan > Halilbey > 7721 > Karadeniz > Kızılırmak > Koral >Neğiş > Aromatik-I and Şumnu > Osmancık-97 > Neğiş> Halilbey > Durağan > 7721> Kızılırmak > Karadeniz > Beşer > Aromatik-I > Gönen > Koral, respectively. According to grain yield, Osmancık-97, Halil Bey, Durağan and Şumnu species are the four best species, whereas Aromatik-I, Koral and Neğiş were the three worst species.

From these results, we conclude that S1 is the most suitable location in increasing grain yield, S2 and S3 classes followed it as well. Halil Bey and Osmancık-97 seem to perform best in increasing grain yield in S1 area. We attribute the differences in efficiency of the different locations to their different suitability class for rice.

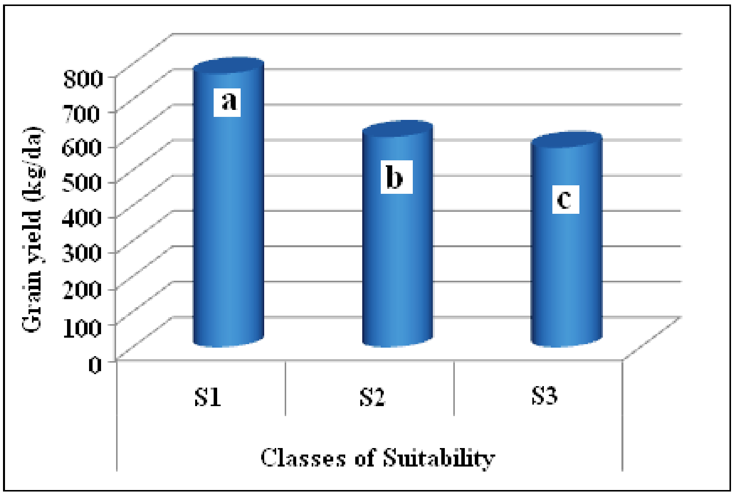

Figure 5. Comparison for general mean grain yield values among land suitability classes of the study area ($LSD_{0.05}$= 11.0)

Table 4. Grain yield values (kg da^{-1}) of rice species growing in Bafra ($LSD_{0.05}$= 53.6)

Class of Suitability	Species	Max.	Min.	SD	Mean
S1	Halil Bey	827.7	771.0	32.7	789.9[a]
	Osmancık-97	766.0	757.4	5.4	760.5[ab]
	Durağan	752.3	748.5	2.2	751.0[b]
	Şumnu	795.0	716.0	45.6	742.3[bc]
	7721	738.6	733.5	2.9	736.9[bc]
	Kızılırmak	755.7	722.4	19.2	733.5[bc]
	Karadeniz	766.7	654.0	65.1	729.1[bcd]
	Gönen	728.1	701.4	15.4	710.3[cde]
	Koral	729.3	675.4	31.1	693.4[def]
	Aromatik-1	701.0	684.5	9.5	690.7[ef]
	Neğiş	701.0	638.8	31.1	670.5[f]
	Beşer	674.8	626.3	28.0	658.6[f]
S2	Osmancık	705.2	680.2	14.4	696.9[a]
	Şumnu	702.6	668.3	17.7	682.8[a]
	Gönen	677.8	651.7	14.1	661.6[ab]
	Beşer	644.2	623.5	12.0	637.3[b]
	Durağan	644.2	614.9	16.9	634.4[b]
	Halil Bey	663.6	562.5	58.4	629.9[b]
	Karadeniz	587.9	563.4	14.1	579.7[c]
	7721	579.6	561.3	9.2	569.7[c]
	Kızılırmak	565.4	558.7	3.5	561.5[c]
	Koral	567.9	520.3	23.8	544.7[c]
	Neğiş	490.5	477.9	6.4	483.7[d]
	Aromatik-1	457.3	430.2	13.7	444.9[e]
S3	Osmancık-97	702.5	688.9	6.8	696.1[a]
	Şumnu	695.6	685.0	6.1	688.8[ab]
	Neğiş	660.5	650.9	5.5	654.1[bc]
	Halil Bey	662.3	629.2	19.1	640.2[cd]
	Durağan	614.8	613.0	1.0	613.6[d]
	7721	560.3	546.8	6.9	552.8[e]
	Kızılırmak	532.6	514.8	10.3	520.7[ef]
	Beşer	517.9	505.0	6.6	512.2f[g]
	Karadeniz	528.3	503.6	14.3	511.8f[g]
	Aromatik-1	477.3	476.0	0.8	476.4[gh]
	Koral	445.0	438.0	4.0	440.3[hi]
	Gönen	470.0	413.0	32.9	432.0[i]

4. CONCLUSION

The study thus confirms the capability of GIS to integrate spatial and attribute data and offers a quick and reliable method of land suitability with higher accuracy. The spatial relationship between different geographically referenced data can be established using a GIS. In addition, the modeling provided an approach to the improvement of rice yield by enhancing the component of modeling input. In the present study soil database and topographic map has been used as vital tools to generate land suitability map. The result presented shows the potentialities and constraints of a region with regard to its land resources and will also be a useful tool for rice cultivation planning.In conclusion, with analysis of spatial modeling it is possible to assess the land suitability with higher accuracy. In addition the modeling provided an approach to the improvement of rice yield by enhancing the component of modeling input.

5. ACKNOWLEDGEMENT

The authors gratefully acknowledge the scientific research grant (TÜBİTAK -107O443) of the Scientific and Technological Research Council of Turkey.

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