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Relationship of Soil Properties with Yield and Morphological Parameters of Pistachio in Geomorphic Surfaces of Bajestan Playa, Northeastern Iran

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ABSTRACT

Pistachio is one of the important and strategic crops in Iran. The objective of this study was to investigate the impact of soil properties on the yield and selected morphological properties of pistachio in Faizabad area, in northeastern Iran. For this purpose, in an area of 20,000 hectares, four geomorphic surfaces were recognized at the margin of Bajestan playa. In each geomorphic surface, three good, medium, and poor quality orchards were identified. A representative soil profile in each orchard was described and sampled. Yield, height, leaf nutrient elements, and morphological properties of three pistachio trees were measured in each orchard. The highest yield (24.5 kg tree^{-1}) was observed in the good orchard in non-saline clay flat geomorphic surface and the lowest (5.2 kg tree^{-1}) was observed in the poor orchard of alluvial fan-clay flat geomorphic surface. Morphological characteristics were in suitable conditions in the good orchard with non-saline clay flat geomorphic surface. The results of correlation and multivariate regression showed that soil salinity (EC), clay content, and soil boron concentration had a significant negative impact on the yield, morphological characteristics, and leaf nutrient elements.

Keywords: Clay flat, Leaf nutrient elements, Soil boron, Soil salinity.

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INTRODUCTION

Pistachio (*Pistachio vera* L.) is one of the most important strategic products of Khorasan Razavi Province, covering 55,000 ha of the province (Ministry of Agriculture Jihad, 2014). Iran, USA, Turkey, Syria and China are the major pistachio producing countries in the world (FAO, 2012).

Pistachio trees are long-lived, so, their planting in suitable soil and water quality conditions would ensure high production capacity (Ferguson, 2005). Hosseinifard *et al*. (2005a) classified the limitations of the pistachio growth into chemical and physical categories in Rafsanjan area. Salinity, sodicity, and high concentrations of Cl and B were the chemical limitations, while heavy soil texture and dense layers (clay, hard and plow pans) were the physical limitations. Pistachio is planted in any type of soil with different textures, but heavy textures don't provide suitable physical conditions for pistachio growth, while the suitable growth is achieved in medium textures such as loamy sand (Ferguson *et al*., 2005; Heydari, 2006; Salehi *et al*., 2009).

Although pistachio is a salt tolerant plant, its growth and yield is severely affected in high soil salinity status (Heydari, 2006; Mohsenian *et al*., 2012). Due to a negative significant correlation between the amount of sodium in the soil solution and pistachio trees growth (Picchioni and Miyamoto,

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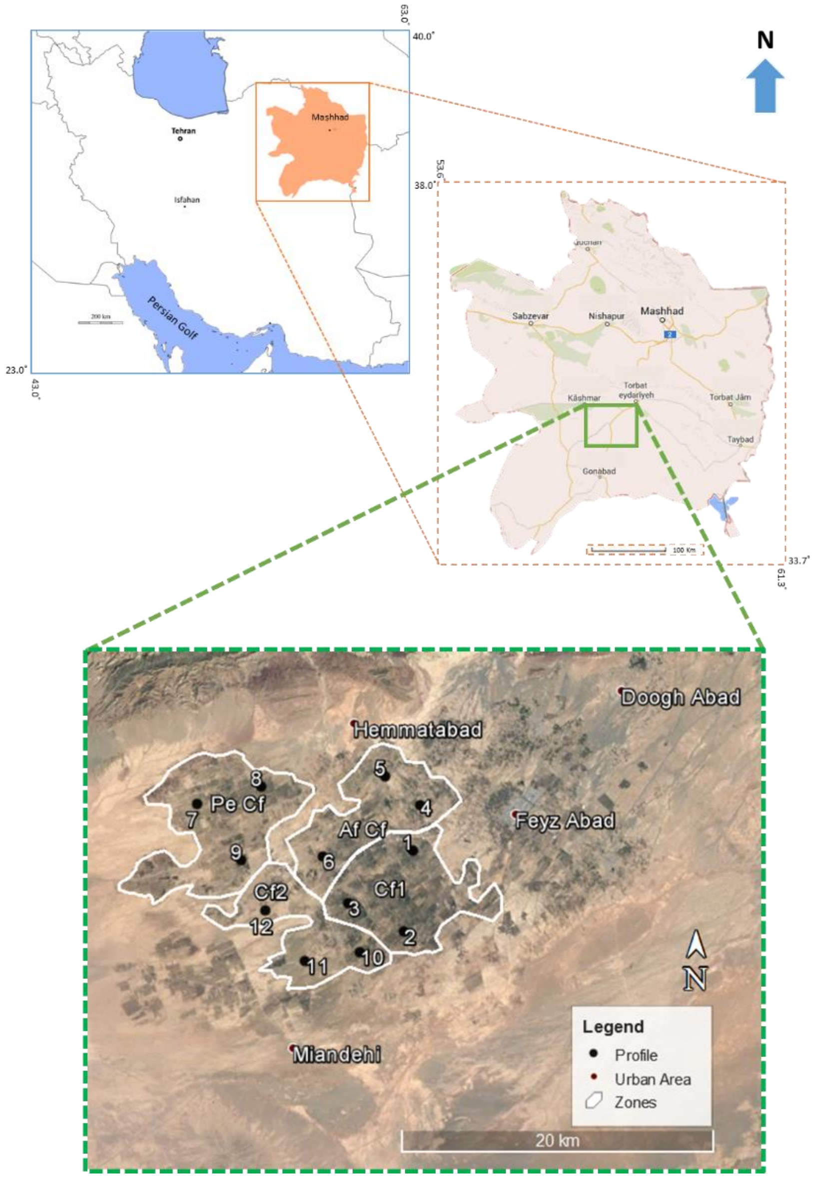

Figure 1.Geomorphic surfaces and location of studied soil profiles in the pistachio cultivation area of Bajestan playa. (Cf1) Non-saline Clay flat; (Af-Cf) Alluvial fan-non-saline Clay flat; (Pe-Cf) Pediment-saline Clay flat, (Cf) Saline Clay falt.

1990), planting pistachio in saline environments increases sodium concentration in aerial parts of the plant, leading to low yield.

Despite the considerable pistachio cultivation areas in Iran, the yield of pistachio per unit area is low. In agricultural systems, soil properties play a determinative role in plants growth. Therefore, the knowledge on the relationship between pistachio cultivation with soil physical and chemical properties could provide information for sustainable land use management. Faizabad Mahvelat is one of the major agricultural regions of Khorasan Razavi Province at the margin of Bajestan playa, which with 35,000 hectares of pistachio orchards has the largest area of pistachio orchards in the province (Ministry of Agriculture Jihad, 2014). The objectives

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of this study were to: (1) Investigate the effect of soil properties on the yield and morphological properties of pistachio trees; (2) Determine the main limiting soil properties affecting the growth characteristics of pistachio, and (3) Identify the relationship between soil properties and leaf nutrient elements concentrations.

MATERIALS AND METHODS

Study Area

The study area (20,000 hectares) is located in Faizabad Mahvelat in southwest of Khorasan Razavi Province at the margin of Bajestan playa, between geographic coordinates of 58˚ 33' to 58˚ 46' E and 34˚ 58' to 35˚ 1' N (Figure 1). The climate of the study area is dry with temperate winters and hot summers. The average annual rainfall and temperature are 193 mm and 17.3°C, respectively. Soil moisture and temperature regimes are weak aridic and thermic, respectively.

Soil and Plant Sampling

From east to west of the region, four geomorphic surfaces, including Alluvial fan- non-saline Clay flat transition (Af-Cf), non-saline Clay flat (Cf1), Pediment-saline clay flat transition (Pe-cf) and saline Clay flat (Cf2) were identified (Figure 1). Based on appearance and yield, three orchards including good, medium, and poor with similar management were selected in each geomorphic surface. The orchards were similar in terms of the cultivars, water quality, irrigation period, and tree age. The studied cultivar in this research was Sefide Badami (dominant cultivar in the region). Trees were 18 to 20 years old and also were in yielding period. Pistachio leaves were collected in July. In each orchard, a representative soil profile was described and sampled from genetic horizons. Three pistachio trees around the representative soil profiles were selected and yield, height, crown and stem diameter, nut splitting, and leaf nutrient elements concentrations of each tree were measured.

Soil Analysis

Air dried soil samples were passed through a 2 mm sieve. Soil texture was determined by hydrometer method (Gee and Buder, 1996), pH was measured in the soil saturation paste and Electrical Conductivity (EC) was measured in 1:5 ratio of soil to water suspension (Thomas, 1996). Calcium carbonate equivalent was measured by acid neutralization method (Page *et al*., 2004). Gypsum content was determined using acetone sedimentation method (Nelson, 1982). Soil organic carbon was measured by wet oxidation method (Nelson and Sommers, 1982). Calcium and magnesium as well as sodium were measured in saturation extract by titration with EDTA and flame photometry, respectively. Total nitrogen and available phosphorous were determined by Kjeldahl (Waling *et al*., 1989) and Olsen (Olsen and Sommers, 1982) methods, respectively. Available potassium and boron were determined by ammonium acetate (Jones, 2001) and Azomethine-H methods (Keren, 1996), respectively. Iron, zinc, manganese and copper elements were extracted using DTPA and were measured by atomic absorption spectrometry (Wright and Stuczynski, 1996).

Plant Analysis

Pistachio leaves were burned in an oven and derived ashes were digested in HCl. Nitrogen and phosphorous were measured by Kjeldahl (Waling *et al*., 1989) and Zerdvanat methods, respectively. Potassium and iron concentrations were measured by flame photometry and atomic absorption

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spectroscopy methods. Boron was determined by Azomethine-H method with a spectrophotometer at 420 nm (Keren, 1996).

Statistical Studies

A nested design with three replications (3 trees) in the three types of orchards, within four geomorphic surfaces was used for statistical analysis using Minitab V.17 software. Duncan's multiple ranges test was applied to examine the differences among the morphological properties of pistachio trees and soil properties. The relationship between morphological characteristics of pistachio trees and soil properties was evaluated through a simple Pearson correlation analysis.

RESULTS

Soil Properties in the Geomorphic Surfaces

Profiles 1, 2, and 3 were in the Cf1 geomorphic surface and composed of cambic (Bw) subsurface horizons (Table 1). Profiles 4, 5 and 6 were in Af-Cf and profiles 7, 8, and 9 in Pe-Cf geomorphic surfaces and composed of Bw and calcic (Bk) horizons. Profiles 10, 11, and 12 were in Cf2 geomorphic surface with Bk, gypsic (By) and salic (Bz) horizons, respectively. Cf2 geomorphic surface was located adjacent to the salt crust of the playa and water table was shallow and the Bz and By horizons formed through the capillary movement.

From alluvial fan to saline clay flat, soil texture became heavier and varied from sandy loam in profile 7 to clay loam in profile 12. In most profiles, silt was the dominant fraction of the soil texture. The amount of calcium carbonate was 11.2 to 25.2% and did not show any variation trend along the geomorphic surfaces. Gypsum was present only as measurable amounts in profiles 4, 11, and 12. In contrast, since soluble salts are easily mobile in the area, the *EC* values gradually increased from 2.1 dS m^{-1} in alluvial fan to 34.7 dS m^{-1} in clay flat.

Yields and Morphological Properties

Results of statistical analysis (Table 2) indicated that yield, morphological properties, and leaf nutrient element concentrations (except P) were significantly different between geomorphic surfaces and orchards. Also, the interaction of different types of orchards and geomorphic surfaces for these parameters are presented in Table 3.

Yield

Mean yield in Cf1 geomorphic (22.62 kg $tree^{-1}$) surface was significantly higher than the other units (Figure 2a). Mean yield in Cf2 geomorphic surface was 9.47 kg $tree^{-1}$ which indicated 58% reduction compared to Cf1 geomorphic surface. There was no significant difference between Af-Cf and Pe-Cf geomorphic surfaces with mean yield of 10.66 and 14.31 kg $tree^{-1}$, respectively.

Mean yield in good and poor orchards was 19.05 and 9.63 kg $tree^{-1}$, respectively. In the medium orchard, the yield was 12.14 kg $tree^{-1}$ (Figure 3-a). The difference between the highest and the lowest yield was 19.34 kg $tree^{-1}$ which varied from 24.5 kg $tree^{-1}$ in good orchard of Cf1 geomorphic surface to 5.2 kg $tree^{-1}$ in the poor orchard of Af-Cf geomorphic surface (Table 3).

Morphological Properties and Nut Splitting

The maximum tree height (259 cm) was found in Cf1 geomorphic surface which was significantly different with the other ones (Figure 2-b). There was no significant difference between other geomorphic surface and the lowest tree height (224 cm) was found in Cf2 geomorphic surface.

Table 1. Selected soil physical and chemical properties of soil profiles.[a]

Geomorphic surface	Profile	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Gravel (%)	pH	*EC* (dS m^{-1})	Na (meq l^{-1})	Ca (meq l^{-1})	Mg (meq l^{-1})	Gypsum (%)	CCE (%)	SOC (%)	*SAR*	B (mg kg^{-1})	Orchard Quality
Cf1	1	A	0-30	48	38	14	-	7.8	2.8	38	35	24	-	18	0.42	6.9	0.8	Medium
		Bw	30-65	45	36	19	-	7.9	3.5	37	31	23	-	19	0.52	7.1	1.6	
		Bk	65-90	41	40	19	-	8.0	2.4	40	36	25	-	21	0.37	7.2	1.3	
		C	90-150	49	36	15	-	7.9	2.1	36	29	19	-	20	0.33	7.3	1.2	
	2	A	0-30	28	52	20	-	7.5	3.3	29	29	16	-	16	0.52	6.1	0.9	Poor
		Bw1	30-80	30	52	18	-	7.5	4.3	29	16	11	-	17	0.22	7.9	1.8	
		Bw2	80-150	35	49	16	-	7.6	4.6	26	19	8	-	17	0.04	7.1	1.6	
	3	A	0-35	23	59	18	-	7.9	2.6	32	36	18	-	16	0.48	6.2	0.8	Good
		Bk1	35-70	22	58	20	-	7.9	3.8	37	34	21	-	22	0.33	7.1	0.9	
		Bk2	70-100	30	54	16	-	7.6	3.5	39	42	22	-	24	0.21	6.9	1.2	
		C	100-150	34	51	15	-	7.7	2.6	38	38	18	-	20	0.14	7.2	0.6	
Af-Cf	4	A	0-35	30	51	19	-	7.5	3.3	38	26	18	-	14	0.11	8.1	1.1	Medium
		Bk	35-75	37	46	17	20	7.6	3.6	39	28	21	2.8	23	0.13	7.8	0.9	
		Bw	75-100	45	39	16	30	7.7	3.7	29	18	17	-	18	0.06	6.9	1.2	
		C	100-150	43	42	15	10	7.7	4.9	34	27	20	-	17	0.04	7.1	1.6	
	5	A	0-30	40	39	21	-	7.9	4.2	48	27	28	-	26	0.21	9.2	1.7	Good
		Bk1	30-70	43	38	19	10	8.0	3.8	59	36	24	-	28	0.19	10.8	1.2	
		Bk2	70-150	42	38	20	-	8.0	3.5	63	38	22	-	29	0.12	11.5	1.1	
	6	A	0-35	38	40	22	-	8.0	5.8	41	30	31	-	22	0.33	7.4	3.6	Poor
		Bw1	35-75	35	39	26	-	7.9	4.3	39	28	30	-	19	0.37	7.2	2.9	
		Bw2	75-120	39	37	24	10	8.0	4.9	35	29	28	-	18	0.21	6.5	3.1	
		C	120-150	38	40	22	-	7.8	3.8	34	30	27	-	17	0.28	6.3	2.6	
Pe-Cf	7	A	0-40	44	40	16	5	7.8	6.6	52	44	27	-	17	0.26	8.7	3.5	Poor
		Bk	40-95	56	33	11	25	7.7	5.3	58	39	29	-	23	0.19	9.9	2.7	
		C	95-150	71	19	10	40	7.9	3.4	49	37	22	-	21	0.07	9.1	2.2	
	8	A	0-20	61	28	11	-	8.0	3.2	44	33	27	-	13	0.54	8.0	0.9	Good
		Bw1	20-50	59	29	12	-	7.9	3.0	41	31	19	-	15	0.48	8.2	0.8	
		Bw2	50-80	68	21	11	-	7.9	3.6	32	29	28	-	12	0.36	6.0	1.2	
		C	80-150	75	14	11	-	8.0	4.1	40	22	17	-	11	0.32	9.1	2.1	
	9	A	0-30	20	57	23	-	7.7	4.2	48	39	21	-	18	0.17	8.7	2.1	Medium
		Bk1	30-90	31	50	19	-	7.7	5.3	44	30	22	-	24	0.13	8.6	2.7	
		Bk2	90-150	32	44	24	-	7.7	4.9	41	33	27	-	22	0.11	7.5	1.8	
Cf2	10	A	0-35	45	35	20	-	7.6	6.9	35	36	18	-	15	0.28	6.7	0.6	Good
		Bk	35-85	51	31	18	5	7.6	4.8	48	41	25	2.1	23	0.17	8.4	1.3	
		C	85-150	36	48	16	-	7.5	4.3	46	39	24	-	16	0.07	8.2	1.4	
	11	A	0-30	25	51	24	-	7.8	34.7	78	29	17	-	17	0.15	16.3	6.7	Poor
		Bz1	30-70	26	53	22	-	7.8	32.5	72	29	19	4.5	19	0.09	14.7	6.2	
		Bz2	70-150	22	56	24	-	7.7	30.2	66	31	20	3.2	18	0.13	13.1	5.1	
	12	A	0-35	41	34	25	-	8.0	10.0	61	26	21	4.2	13	0.05	12.6	4.6	Medium
		By	35-80	39	38	23	-	7.9	9.5	68	29	22	8.1	19	0.08	13.5	3.8	
		C	80-150	44	37	19	-	8.0	13.0	76	32	21	5.2	13	0.04	14.8	5.1	

[a] CCE: Calcium Carbonate equivalent; SOC: Soil Organic Carbon, SAR: Sodium Absorption Ration.

Table 2. Analysis of variance of yield and pistachio properties for different orchard quality in geomorphic surfaces.

Source	*Df*	Yield	Tree height	Crown diameter	Trunk diameter	Splitting	N	P	K	Fe	B
		(kg tree^{-1})	(cm)				(%)			(mg kg^{-1})	
Geomorphic surface	3	317.3**	2178.4**	5023.4**	86.7**	214.8**	1.8**	0.04^{ns}	1.06**	11862.2*	5054.0**
Geomorphic surface×Rep	8	0.44	135.5	24.2	2.15	4.19	0.14	0.02	0.09	380.4	361.5
Orchard quality	2	226.3**	1682.6**	2635.8**	58.8**	163.1**	1.7**	0.04^{ns}	0.72*	3532.6**	2923.6^{ns}
Geomorphic surface×Orchard quality	6	34.3**	257.7**	435.4**	11.1**	34.4**	0.35*	0.02*	0.16*	1562.7*	2737.2*
Error	16	1.43	46.5	72.6	1.8	6.11	0.14	0.018	0.18	451.3	908.4
CV%		8.38	2.88	3.53	5.98	2.85	18.86	57.84	32.80	13.92	17.35

* and **: Significant at 5 and 1% probability levels, respectively, ^{ns}: Non-significant.

Table 3. Means comparison of yield and pistachio trees properties of different orchards quality in geomorphic surfaces.^{a}

Geomorphic surface	Orchard quality	Yield	Height	Crown diameter	Trunk diameter	Splitting	N	P	K	Fe	B
		(kg tree^{-1})	(cm)				(%)				(mg kg^{-1})
	Good	24.5^{a}	263.0^{a}	280.6^{a}	26.0^{a}	78.0^{e}	2.87^{a}	0.43^{a}	1.71^{a}	202.7^{a}	145.7^{cd}
Cf1	Medium	21.5^{b}	254.6^{ab}	270.0^{a}	27.4^{a}	81.3^{cd}	2.80^{a}	0.22^{cab}	1.73^{a}	186.7^{ab}	162.3^{bcd}
	Poor	21.9^{b}	258.6^{a}	273.6^{a}	26.6^{a}	80.0^{de}	2.43^{ab}	0.32^{cab}	1.54^{ab}	215.0^{a}	154.0^{bcd}
	Good	13.6^{cd}	235.6^{c}	237.3^{b}	23.3^{b}	83.6^{bc}	2.04^{bc}	0.18^{cab}	1.53^{ab}	158.3^{bc}	164.3^{bcd}
Af-Cf	Medium	13.2^{d}	232.3^{c}	232.0^{b}	20.6^{cd}	87.6^{c}	2.06^{bc}	0.14^{cb}	1.51^{ab}	145.7^{cd}	163.7^{bcd}
	Poor	5.2^{f}	214.0^{d}	212.6^{c}	18.0^{e}	90.2^{b}	1.49^{cd}	0.38^{ab}	0.73^{c}	97.0^{e}	139.0^{d}
	Good	22.6^{b}	256.0^{ab}	272.33^{a}	26.6^{a}	80.0^{de}	2.87^{a}	0.26^{cab}	1.70^{a}	190.7^{ab}	163.7^{bcd}
Pe-Cf	Medium	14.4^{cd}	237.6^{c}	237.6^{b}	22.0^{bc}	81.6^{cd}	2.08^{bc}	0.17^{cb}	1.68^{a}	160.3^{bc}	194.0^{bc}
	Poor	5.9^{ef}	213.6^{d}	213.3^{c}	18.6^{de}	85.0^{d}	1.18^{d}	0.12^{cb}	0.99^{cab}	120.3^{ed}	185.3^{bcd}
	Good	15.4c	241.3c^{b}	240.0^{b}	22.6^{bc}	91.3^{ab}	1.71^{cd}	0.28^{cab}	1.0^{cab}	133.7^{ecd}	150.0^{bcd}
Cf2	Medium	7.4e	216.6^{d}	212.3^{c}	18.6^{de}	95.0^{a}	1.65^{cd}	0.13^{cb}	0.72^{c}	102.3^{e}	199.3^{b}
	Poor	5.6ef	215.3^{d}	214.6^{c}	17.6^{e}	95.1^{a}	1.25^{d}	0.11^{c}	0.84^{cb}	118.3^{ed}	262.7^{a}

^{a} Mean values by different letters are significantly different (P< 0.05).

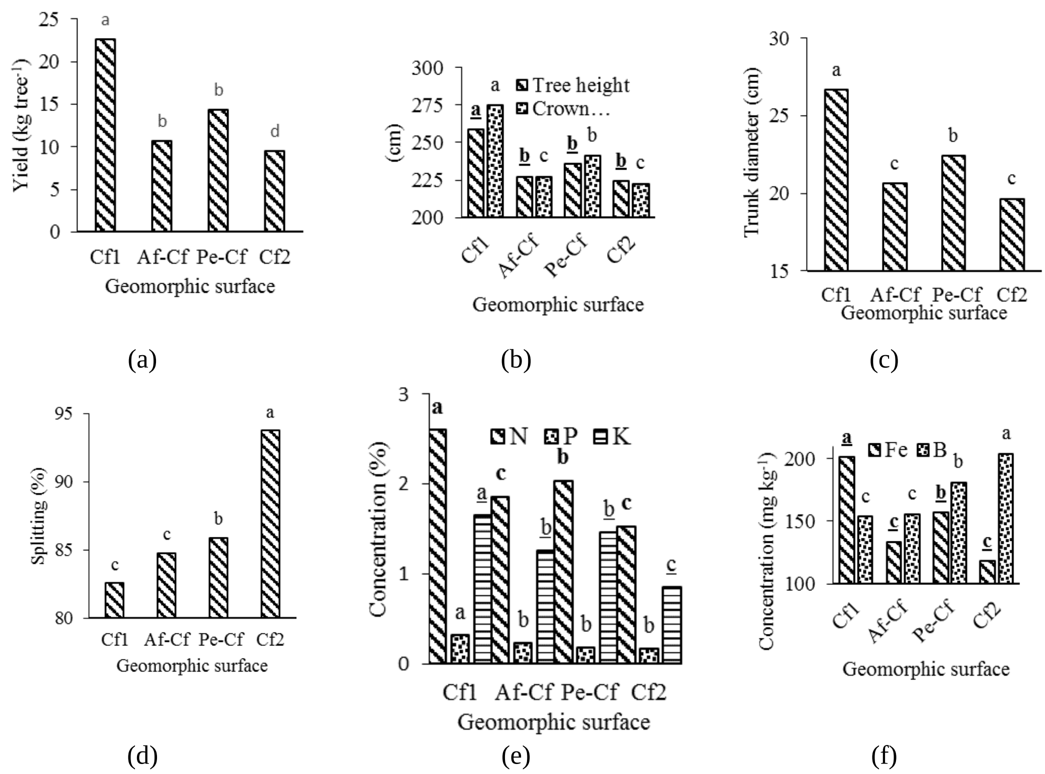

Figure 2. Histograms of mean yield, morphological properties, and leaf nutrient elements concentration in different geomorphic surfaces.

The highest and lowest mean crown diameter (275 and 222 cm) occurred in Cf1 and Cf2 geomorphic surface, respectively (Figure 2-b). The trunk diameter in the Cf1 geomorphic surface was 26.7 cm that was significantly different with the value of 19.7 cm in the Cf2 geomorphic surface (Figure 2-c). The highest and lowest nut splitting were 93.8 and 82.6% in Cf2 and Cf1 geomorphic surfaces, respectively (Figure 2-d).

The highest and lowest tree height with values of 249 and 225 cm was observed in good and poor orchards, respectively (Figure 3-b). Similar results were found for crown and trunk diameter. The lowest and highest values of crown and trunk diameters were 22.8 to 25.7 cm and 20.2 to 27.7 cm (Figures 3-b and -c). The nuts splitting percentage in the good orchard was 83.7% and increased to 90.8% in the poor orchard (Figure 3-d). There was no significant difference between the good and medium orchards in terms of splitting percentage.

The interaction effects of the surfaces in orchard type showed that the highest tree height, crown and trunk diameter, and nut splitting occurred in good orchard of Cf1 geomorphic surface. The lowest values of these characteristics were found in poor and medium orchards of Cf2 geomorphic surface.

Leaf Nutrient Elements Concentrations

The highest amount of leaf N, P, K, and Fe were found in the Cf1 and the lowest amount occurred in the Cf2 geomorphic surface (Figures 2-e and -f). The lowest leaf B concentration (154 mg kg^{-1}) was in the Cf1 and the highest concentration (204 mg kg^{-1}) occurred in Cf2 geomorphic surfaces (Figure 2-f). Except B, the highest nutrient concentrations were recorded in the orchards of good quality (Figures 3-e and -f). The highest and lowest leaf B concentrations were 185.2 and 155.9 mg kg^{-1} which were

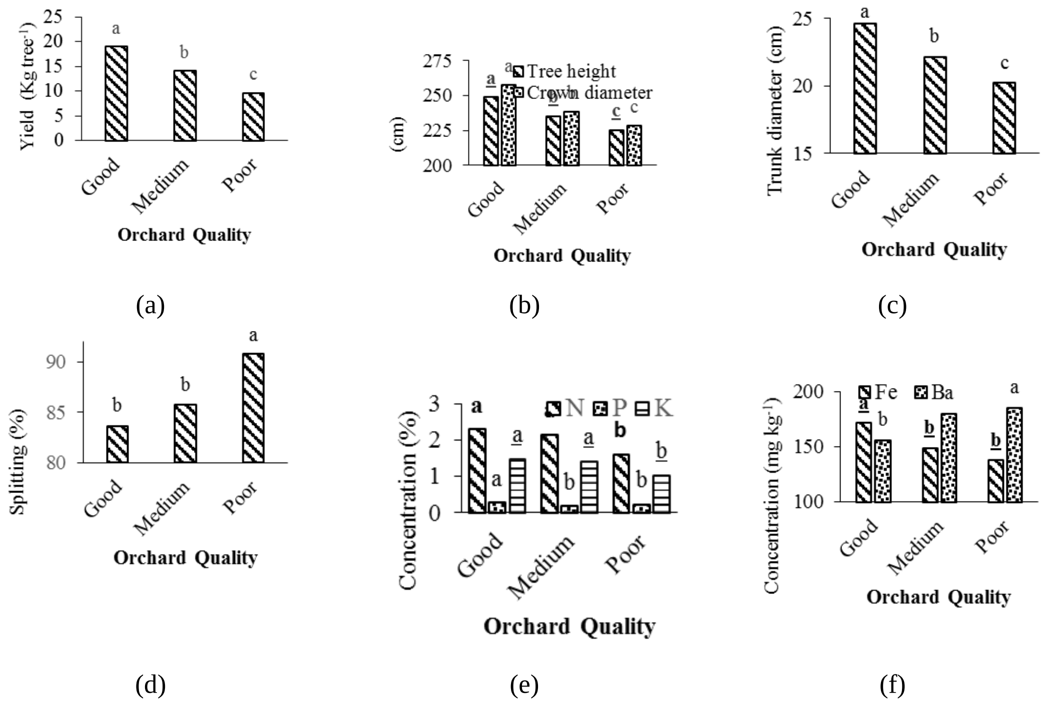

Figure 3. Histograms of mean yield, morphological properties, and leaf nutrients element concentrations in different orchards.

observed in poor and good orchards, respectively (Figure 3-f).

The maximum content of nitrogen (2.87%) occurred in good orchard of Cf1 geomorphic surfaces and the lowest concentration of this element (1.18%) was observed in the poor orchard of Pe-Cf geomorphic surfaces. The highest amount of P (0.43%) was observed in the good orchard of Cf1 geomorphic surfaces and the lowest amount (0.11%) was observed in the poor orchard of Cf2 geomorphic surfaces (Table 3). The highest concentration of K (1.73%) was found in the "medium" orchard of Cf1 geomorphic surfaces and the lowest concentration (0.72%) was observed in medium orchard of Cf2 geomorphic surfaces. The highest Fe concentration (202.6 mg kg^{-1}) was observed in good orchard of Cf1 geomorphic surface, and the lowest concentration (102.3 mg kg^{-1}) was observed in medium orchard of Cf2 geomorphic surfaces. The highest concentration of B (262.6 mg kg^{-1}) was observed in poor orchard of Cf2 geomorphic surfaces and the lowest concentration (97 mg kg^{-1}) was observed in poor orchard of Pe-Cf geomorphic surfaces (Table 3).

DISCUSSION

Yield and Soil Properties Relationship

There was a positive and significant correlation between yield, height, crown and trunk diameters (P< 0.01) (Table 4). Higher nut production is expected with increasing the height, crown and trunk diameter.

Significant positive correlation was found between yield and the concentration of soil nutrients elements, with the exception of B which had a negative significant correlation (P< 0.01). The correlations for N and Fe were stronger than K and P. It can be attributed to lower range variations of K and P in the areas [Figures 3 (e and f) and 2 (e and f)]. Ferguson *et al*. (2005) reported B concentration in the pistachio leaves up to 120 mg kg^{-1} and stated that concentrations

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Table 4. Pearson correlation between properties of pistachio trees in the study area.

Characteristics	Yield	Height	Crown diameter	Trunk diameter	Splitting	N	P	K	Fe
Tree height	0.95**								
Crown diameter	0.96**	0.94**							
Trunk diameter	0.94**	0.88**	0.86**						
Splitting	0.95*	0.94*	0.94*	0.92*					
N	0.84**	0.77**	0.83**	0.84**	0.86**				
P	0.43**	0.39*	0.45**	0.34*	0.41*	0.35*			
K	0.68**	0.61**	0.66**	0.73**	0.63**	0.67**	0.25^{ns}		
Fe	0.88**	0.88**	0.88**	0.83**	0.85**	0.74^{ns}	0.29^{ns}	0.70^{ns}	
B	-0.45**	-0.44**	-0.38**	-0.44**	-0.45**	-0.35*	-0.61**	-0.27^{ns}	-0.36*

* and **, Significant at 5 and 1% probability levels, respectively, ^{ns} Non-significant.

more than 200 mg kg^{-1} cause a sharp decline in the growth and yield.

There was a negative and significant relationship (P< 0.01) between the yield and *EC*, B concentration and clay content, while there was a positive and significant relationship (P< 0.01) between the yield and the amount of K, sand, and Soil Organic Carbon (SOC) (Table 5). These results are consistent with the results of Salehi and Hosseinifard (2012). Due to high *EC* values and B concentration in profiles 11 and 12 which were located on Cf2 geomorphic surface, the reduction in yield and growth of pistachio was expectable. By increasing salinity, the osmotic pressure increases and water and nutrients uptake by plants is decreased, resulting in yield reduction (Goldhamer, 2005; Shahriarpour *et al*., 2011; Fekri and Soleimanzadeh, 2016). Furthermore, in saline soils, the toxicity of Na and B cause the growth and yield decline (Heydari, 2006). Salinity stress decreases plant water content and limits cell elongation; and even after the osmotic adjustment, cell enlargement and elongation would be slow (Shahriarpour *et al*., 2011). *EC* values up to 8 dS m^{-1} do not have any effect on pistachio plant growth, and for *EC* between 12 to 18 dS m^{-1} m pistachio cultivation is justifiable. At *EC* more than 18 dS m^{-1}, the yield reaches zero, however, the trees survive (Zeinadin *et al*., 2009). As the density of the roots of mature trees are at depths of more than 40 cm (Hosseinifard *et al*., 2010), and according to the tolerant level of pistachio trees, it is likely that increasing salinity in the deeper layers would be among the most important factors for yield reduction in Rafsanjan (Eskandari and Mozaffari, 2014).

There was a negative and significant correlation between the yield and Na and Cl concentrations and *SAR* (P< 0.05) (Table 5). By increasing soil salinity, the concentrations of soluble salts increased in the Cf2 geomorphic surface, and the absorption of Na and B increased. Reduction in shoot and roots growth of pistachio trees with increase in soil salinity has been proven. Salinity has been considered one of the most important factors which cause imbalance in the plant nutrients and reduce the amount of leaf chlorophyll and, consequently, reduce photosynthesis (Muns and Tester, 2008). In most of the studied profiles, the amount of *SAR* in the surface layers was less than the subsurface layers. The amount of this parameter varied from 8.5 to 70 in the surface layers. Hosseinifard *et al.* (2005 a) studied the quality of soils in the pistachio orchards of Rafsanjan and concluded that in most of these soils high *EC* values and Na, Mg, and Cl and low K concentration are the most limiting growth factors. The reported critical level of *SAR* for pistachio is 15 (Ferguson, *et al*., 2005).

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Table 5. Pearson correlations between soil properties, yield, and morphological properties of pistachio trees.[a]

Soil characteristic	Yield	Height	Crown diameter	Trunk diameter	Splitting	pH	*EC*	Gypsum	SOC	Sand	Silt	Clay	K	Fe	Mn	Zn	Cu	Na	Cl	*SAR*
pH	-0.25*	-0.24*	-0.23*	-0.31*	-0.28*															
EC	-0.48**	-0.32*	-0.36*	-0.33*	0.32*	0.32*														
Gypsum	-0.19^{ns}	-0.21^{ns}	-0.25^{ns}	-0.08^{ns}	-0.19^{ns}	0.23^{ns}	-0.30*													
SOC	0.47**	0.56**	0.51**	0.39*	0.44*	0.02^{ns}	-0.30^{ns}	-0.34^{ns}												
Sand	0.46**	0.39*	0.34*	0.29*	-0.25^{ns}	0.11^{ns}	0.20^{ns}	0.15^{ns}	0.21^{ns}											
Silt	-0.39*	-0.32*	-0.38*	-0.41*	-0.35*	-0.24^{ns}	0.25^{ns}	-0.16^{ns}	-0.19^{ns}	-0.95**										
Clay	-0.41**	-0.39*	-0.38*	-0.29*	-0.36*	-0.22^{ns}	0.22^{ns}	-0.07^{ns}	0.09^{ns}	-0.72**	0.47**									
K	0.63**	0.64**	0.63**	0.47**	-0.54**	0.04^{ns}	-0.23^{ns}	-0.27^{ns}	0.57**	-0.35^{ns}	0.09^{ns}	0.25*								
Fe	0.45*	0.51**	0.45*	0.36*	-0.42**	-0.17^{ns}	-0.29^{ns}	-0.29^{ns}	0.41*	-0.47**	0.24*	0.12^{ns}	0.62**							
Mn	0.40*	0.41*	0.35*	0.31*	-0.39*	-0.23^{ns}	-0.32^{ns}	-0.43*	0.39*	-0.62**	0.23*	0.06^{ns}	0.52**	0.65**						
Zn	0.45*	0.44*	0.46*	0.41*	-0.38**	0.22^{ns}	-0.39*	-0.25^{ns}	0.49**	-0.24^{ns}	-0.09^{ns}	0.02^{ns}	0.61**	0.62**	0.55**					
Cu	0.42*	0.47**	0.41*	0.36*	-0.40*	-0.12^{ns}	-0.48**	-0.51**	0.52*	-0.41*	0.14^{ns}	0.11^{ns}	0.62**	0.78**	0.65**	0.68**				
Na	-0.45*	-0.19*	-0.28*	-0.38*	0.31*	0.54**	0.79**	0.58**	-0.32*	-0.05^{ns}	0.12^{ns}	0.24^{ns}	-0.15^{ns}	-0.37*	-0.31^{ns}	-0.16^{ns}	-0.49**			
Cl	-0.36*	-0.25*	-0.26*	-0.29*	0.35*	0.43*	0.57**	0.66**	-0.44*	-0.07^{ns}	0.06^{ns}	0.26^{ns}	-0.17^{ns}	-0.31^{ns}	-0.34^{ns}	-0.12^{ns}	-0.42*	0.69**		
SAR	-0.39*	-0.35*	-0.32*	-0.41*	0.41*	0.45*	0.89**	0.63**	-0.39*	-0.11^{ns}	0.15^{ns}	0.26^{ns}	-0.22^{ns}	-0.37^{ns}	-0.33^{ns}	-0.28^{ns}	-0.53**	0.95**	0.73**	
B	-0.469*	-0.31*	-0.38*	-0.37*	0.389*	0.320*	0.84**	0.321*	-0.37*	-0.41*	0.477*	0.57**	-0.37^{ns}	-0.38^{ns}	-0.37^{ns}	-0.30^{ns}	-0.47**	0.74**	0.55**	0.80**

[a] CCE: Calcium Carbonate Equivalent; SOC: Soil Organic Carbon, SAR: Sodium Adsorption Ration, * and **: Significant at 5 and 1% probability levels, respectively; ^{ns}: non-significant.

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Usually, by increasing the clay content, the pistachio yield would be decreased (Hosseinifard *et al*., 2005c). These observations can be justified because by increasing clay content, the permeability decreases and soil becomes harder and aeration and root penetration become difficult. As presented in Table 1, Profile 6 that is located in poor orchards contains high clay content.

Averages of K concentration in the Cf1 and Af-Cf geomorphic surfaces were 350 and 168 mg kg^{-1}, respectively. Significant positive relationship was observed between yield and soil K (Table 5). Due to the high amount of K in the soils of orchards in Cf1 geomorphic surface, high level of yield was achieved. Also, high amount of Na in the soils of Cf2 geomorphic surface and its competition with K for uptake by the plant (Hosseinifard *et al*., 2005a) resulted in decreased absorption of K and, therefore, reduction in the yield. Hosseinifard *et al.* (2010) studied the forms of potassium in soils of pistachio trees in Rafsanjan and found that in the soils with low content of exchangeable K, a reduction between 2 and 20% in pistachio yield was observed. There is a positive correlation between the concentration of leaf K and the yield and more than 90% of K uptake by the tree was observed during growth stage of seed. For this reason, the K fertilizing at nut filling stage helps in increasing yield and decreases splitting (Zeng *et al*., 1998). High concentrations of NaCl in the soils or in the irrigation water leads to a decrease in leaf K concentration (Saadatmand *et al*., 2008).

There was a positive and significant correlation between the concentration of leaf and soil B concentrations (Table 4) which indicated the close relationship of B in the soil and plant. There was a negative correlation between the yield and the amount of soil B (Table 5) positive correlation between B and *EC* (Figure 4). Due to lack of suitable drainage in the orchards of Cf2 geomorphic surface, the concentration of B in this soil was high. The acceptable limit of B concentration in the soil for pistachio is reported equal to 0.8 to 1 mg kg^{-1} (Hosseinifard *et al*., 2005b) and even concentrations up to 5 mg kg^{-1} have been reported (Ferguson, 2005). The average amount of B in the studied soils was 2.2 and its maximum was 6.7 mg kg^{-1}, which is much higher than the acceptable limit. The studies on the areas under pistachio cultivation in Iran represent the toxicity of B in these areas; on the other hand, the presence of calcium carbonate in the soils of these areas can reduce B bioavailability due to surface adsorption (Hosseinifard *et al*., 2008). In the presence of large amounts of B in the soil, root growth becomes limited and photosynthesis is disrupted (Koukoulakis *et al*., 2013). According to these results, the high concentration of B in the soil can be one of the factors influencing the reduction of growth and the yield of pistachio in medium and poor orchards of profiles 11 and 12 in Cf2 geomorphic surface.

There was a significant positive correlation between yield and Fe, Mn, Zn, and Cu. Soils of arid environments of Iran are calcareous and high soil pH limits the bioavailability of Fe, Mn, Zn and Cu and, consequently, causes deficiency of these elements for the plants (Kamali and

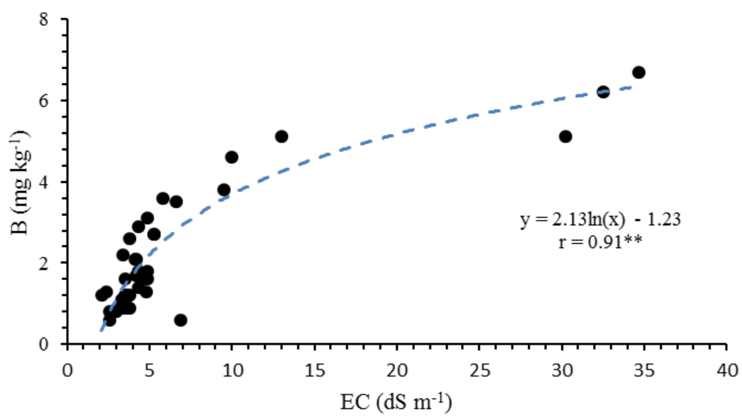

Figure 4. The relationship between salinity and soil B concentration in the studied soils.

Owji, 2016). Low concentrations of Fe and Mn in the leaves and Ca in the endocarp as well as special properties of the soil such as soil texture and structure, the amount of gypsum, soil layers and percentage of gravel correlate to the low quality of pistachio and early splitting phenomenon of pistachio nut (Hosseinifard and Panahi, 2006). Some studies have shown that pistachio is sensitive to gypsum and its acceptable upper limit is 2% (FAO, 2012). Increase in the solubility of soil Ca due to the presence of gypsum may result in a decline in the bioavailability of Zn, Fe, and Mn. In addition, maintenance, absorption and water movement in gypsic soils is decreased due to the effect of gypsum on the structural units of the soil (Hosseinifard *et al.*, 2005c).

Correlation between Morphological Parameters and Soil Properties

Higher tree height in Cf1 geomorphic surface represents the suitable properties for plant growth in this unit. It seems that pistachio trees have limited their aboveground growths to make adaption with non-favorable soil properties, especially salinity, high B concentration, and heavy soil texture (Karimi *et al*., 2009; Benmahioul *et al*., 2009). It was found that salinity reduces the amount of chlorophyll content probably through the destruction of chloroplast membrane (Najafian *et al*., 2008). By increasing salinity in the root zone, the leaf appearance is delayed or stopped and fewer lateral branches would be produced (Muns and Tester, 2008). The results have shown that there is a positive and significant correlation between tree height and soil organic carbon, nitrogen, potassium, iron, and copper (P< 0.01). The correlation between crown diameter and soil organic carbon and potassium is positive and significant (P <0.01). Among the soil properties, only soil K showed a significant positive correlation with the trunk diameter tree height and crown diameter and negative correlation with splitting at P< 0.01 (Table 5). Potassium affects plant photosynthesis and, therefore, can increase leaf chlorophyll and subsequently increases crown diameter and trunk diameter (Havlin *et al*., 2014).

The better morphological characteristics in Cf1 and Pe-Cf geomorphic surfaces are probably due to higher N and K in the soil. N is one of the important elements for improving the vegetative growth and pistachio tree height. N is very effective in stimulating the formation of flower buds, causing faster growth of leaf area, and increasing photosynthesis, better formation of fruit, and preventing shedding of buds (Mozafari *et al*., 2005). Micronutrients are essential for growth and development of pistachio and their major role is that of activating the plant enzymes. However, due to soil limitations in the areas, deficiency of micronutrients such as Fe and Zn can reduce vegetative growth and limit quality of pistachio (Hosseinifard and Panahi, 2006).

There was a negative significant correlation between splitting with K, Fe, and Zn (P< 0.01) and a positive significant correlation between the splitting and *EC*, SOC, Mn, and Cu. Also, a significant negative correlation was found between splitting with the soil clay content (P< 0.05) (table 5). Higher splitting values in orchards of Cf2 geomorphic surface is probably due to the unfavorable condition of soil fertility and plant nutrition and the toxicity of B. Negative relationship of potassium with splitting could be attributed to positive relationship of potassium with clay content. Because, high amount of clay reduces the tree growth and root penetration and absorption of nutrients which affect the quality of pistachio. Iron plays a key role in the synthesis of chlorophyll and also K increases photosynthesis and transfer of materials to fruits and reduce the early splitting (Zeng and Brown; 2001).

Hosseinifard and Panahi (2006) studied the effects of some nutrients on splitting of pistachio nut and showed that early splitting had a significant negative correlation with Fe content in the leaves and the ratio of Fe to other elements. Heydari (2006) showed

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that the splitting, growth index, and trunk diameter are negatively correlated with clay content which is the most important factors on the yield and quality of pistachio.

The results of multivariate regression analysis revealed that *EC* and clay content were the most important factors affecting the pistachio yield (Table 6). Based on regression analysis of morphological properties studied in pistachio orchards, *EC*, clay content, and B concentration had the partial coefficient of determination of 51, 30, and 10%, respectively; thus, they were the most important determinants of pistachio yield in the studied orchards. The amount of soil B with 1% as the third attribute was entered in the regression model and the efficiency was increased to 96%. The results of this study are consistent with the results reported by Salehi *et al*. (2009).

CONCLUSIONS

The results of this study showed that the yield of pistachio in the studied area varied from 9.47 to 22.62 kg $tree^{-1}$. Also, morphological properties of the trees and concentrations of nutrient elements in the pistachio leaves indicated high variability in the area. Soil properties in the study area showed a lot of changes. Among the soil properties, concentrations of N, P, K, Fe, and B as well as *EC* and clay content had the most effects on the growth characteristics of pistachio. The results of the correlation studies showed the positive effects of nutrient elements concentrations and the negative effects of *EC*, clay content, and concentration of B on the yield and morphological properties of pistachio. *EC*, clay content, and B concentration in the soil were the most important determinants on the growth and yield of pistachio trees.

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Table 6. Stepwise regression analysis of pistachio yield and soil properties.

Step	Entered property	Number R^2	Partial R^2	*F* Value	*Pr> F*
1	*EC*	0.51	0.51	352.8	0.0001**
2	Clay	0.30	0.81	20.16	0.0001**
3	B	0.10	0.91	4.50	0.06*
4	K	0.05	0.915	3.38	0.07*
5	Mn	0.01	0.916	2.56	0.12 ns

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ارتباط ویژگی‌های خاک با عملکرد و ویژگی‌های موفولوژیک پسته در سطوح ژئومورفیک پلایای بجستان، شمال شرق ایران

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چکیده

پسته یکی از مهم‌ترین محصولات مهم و استراتژیک در ایران است. هدف از این مطالعه بررسی تاثیر ویژگی‌های خاک بر عملکرد و ویژگی‌های مورفولوژیک پسته در فیض‌آباد در شمال شرق ایران بود. برای این منظور، در منطقه‌ای به وسعت 20000 هکتار، چهار سطح ژئومورفیک تعیین شد. در هر سطح ژئومورفیک، سه نوع باغ خوب، متوسط و ضعیف شناسایی شد. در هر باغ یک خاکرخ شاهد تشریح و نمونه‌برداری شد. عملکرد، ارتفاع، عناصر غذایی برگ و برخی ویژگی‌های موفولوژیک سه درخت در اطراف هر خاکرخ اندازه‌گیری شد. بیشترین مقدار عملکرد با مقدار 24/5 کیلوگرم در هر درخت در باغ خوب و سطح ژئومورفیک کفه رسی غیرشور مشاهده شد. کمترین مقدار عملکرد 5/2 کیلوگرم در هر درخت بود که در باغ ضعیف سطح ژئومورفیک کفه رسی شور مشاهده شد. ویژگی‌های مورفولوژیک درختان پسته در باغ خوب سطح ژئومرفیک کفه رسی غیرشور، در شرایط مناسبی قرار داشتند. نتایج آنالیز رگرسیون چند متغیره نشان داد که هدایت الکتریکی (EC)؛ مقدار رس و غلظت بر تاثیر منفی بر عملکرد و خصوصیان موفولوژیک پسته و غلظت عناصر در برگ داشت.

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