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Mycorrhizal efficiency in pepper yield by fertilization in clay soil growth conditions

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Abstract

Biomass responses to mycorrhizae and fertilization of phosphorus (P) and elemental sulfur (ES) on green pepper (*Capsicum annuum L.*) grown for 45 days on calcareous sterilized Menekşe soil (sub-group Typic Xerorthent) were investigated. Root yield was increased by mycorrhizal inoculation compared to the control treatment. However, shoot yield remained unchanged. On the other hand, there was more synergistic effect between mycorrhizae and combined fertilization of ES and P, compared to the ES or P fertilization alone. Accordingly, shoot concentrations of P significantly increased. The other shoot nutrient concentrations differed independently from each other as statistically significant. Results showed that P and ES fertilization increased the efficieny of mycorrhizae in the clay soil growth conditions and mycorrhizae has potential to increase yield.

Key words: Mycorrhizae; elemental sulfur; phosphorus; shoot nutrient concentrations; pepper

INTRODUCTION

Mycorrhizae as a kind of substitute of plant root in the nutrient uptake for plant growth has different interactions in changing growth medium conditions, resulting in the differences in the productivity of natural plant production system. Understanding of those interactions may clarify mycorrhizal benefits to ecological agriculture. Mycorrhizal inoculation increases yield (Karaca, 2012a; Karaca, 2013; Karaca et al., 2013). Similarly, P fertilization results in significant yield increases. On the other hand, in clay textured soil, P and mycorrhizae addition in combination compared to P addition alone results in significant shoot yield decrease while the reverse is the case for the root yield. (Karaca et al., 2013). Both mycorrhizal inoculation and its effect by P applications increases yield (Ortas et al., 1996; Karaca, 2012a).

Mycorrhizal inoculation increases yield but S fertilization has no effect on the yield (Guo et al., 2005). ES fertilization affects the yield in both directions (Karaca, 2012b). S fertilization has no effect (Hoffman et al., 1998) or increases yield (McLaughlin and Holford 1982; Merrien, 1987). Oxidation products of ES decreases soil pH that gradually increases solubility of plant nutrients. Heavy metal concentration, if present, can increase by the decreased soil pH resulting in yield decrease (Cui et al., 2004).

Mycorrhizal inoculation induces higher shoot and root yield. Root to shoot ratio decreases or remains around at the same level while shoot P concentration increases or remains around at the same level depending on the mycorrhizal species (Ortas et al., 2002). Mycorrhizal inoculation alone compared to the control treatment results in increased or unchanged root to shoot ratio. However, those ratios are in both directions in the case of ES and/or P additions. (Karaca, 2012a). Romero et al., (1996) proposed that there may be an optimum root to shoot ratio for plant growth.

Mycorrhizal inoculation alone compared to the control treatment decreases the shoot P concentrations (Karaca, 2012a). There is no correlation, all the time, between increased P uptake and P concentration in plant dry matter (Menge et al., 1978; Raj et al., 1981; Yibirin et al., 1996; Karaca, 2012a; Karaca, 2012b; Karaca et al., 2013). With small additions of P fertilizer, entry points and fungal growth on the root surface remains normal but arbuscles are small and even fewer in number, reducing the effectiveness of fungus/plant relationship. Mycorrhizal infections tend to stop in soils containing or given high P (Baylis, 1967; Mosse, 1967; Karaca, 2012a). ES fertilizations does not affect the root mycorrhizal infection level but can compensate the decreasing effect of P fertilization on the root mycorrhizal infection level and can increase efficient work of mycorrhizae for the yield (Karaca, 2012a). A slight reduction on percentage of mycorrhizal colonization was noted with SO_2 (Diaz et al., 1996).

This study evaluates the effects of ES and/or P on mycorrhizae for the yield, shoot nutrient concentrations, and changes in the root morphology of pepper in clay soil growth conditions.

MATERIAL AND METHOD

Surface soil samples (0-30 cm) for Menekşe soil were taken from the non cultivated part of the Cukurova University experimental farm. The soil Menekşe serial was a typic Xerorthent of the Entisol ordo in the Soil Taxonomy (Özbek et al., 1974). The plot had not been cultivated for many years. Air dried soil samples were crushed, sieved (2 mm mesh opening) and autoclaved at 121ºC for two hours prior to use as a growth medium. The pots surface were sterilized with ethanol 96 % (v/v), washed by distilled water and dried out prior to the use. 4 kg of autoclaved soil were placed in the plastic pots and following treatments were made.

MoPoSo: Control application in which 500 mg kg^{-1} N (as urea), 250 mg kg^{-1} K (as KNO_3), 5 mg kg^{-1} Zn (as $ZnSO_4$) and 20 mg kg^{-1} Fe (as Fe-EDDHA) were put into the pots, and then soil samples were thoroughly mixed.

MoPoS+: 100 mg kg^{-1} ES was added to the control treatment.

MoP+So: 100 mg kg^{-1} P (as triple super phosphate) was added to the control treatment.

MoP+S+: 100 mg kg^{-1} P and 100 mg kg^{-1} ES were added to the control treatment.

M+PoSo: *Glomus mossea* AM fungi type as the mycorrhizae (as 145 g soil taken from the vicinity of the dead vineyard roots at the University Farm for the average 1000 spore/pot inoculation) was added to the control treatment. The mycorrhizal density of soil was determined by the method of Gerdemann and Nicolson (1963).

M+PoS+: The mycorrhizae and 100 mg kg^{-1} ES were added to the control treatment.

M+P+So: The mycorrhizae and 100 mg kg^{-1} P were added to the control treatment.

M+P+S+: The mycorrhizae, 100 mg kg^{-1} P and 100 mg kg^{-1} ES were added to the control treatment.

All fertilizers were mixed thoroughly in the soil. However, the mycorrhizal inoculum was mixed into the top 5 cm of the soil. Following the addition of the inoculum, 1000 ml water was added to the each pot to bring the soil about field capacity and allowed to drain for 5 days.

Green pepper seeds (*Capsicum annuumL.*) were sown into sterilized growth medium of soil and organic matter mixture (soil/organic matter: 2/1 (v/v) and grown for 35 days. The seedlings were carefully extracted from the nursery and transplanted into the pots and irrigated when required. The seedlings grew for one and half month. The plants were harvested by cutting just above the soil level and the shoots were separately dried at 75ºC to a constant weight after clearing possible contaminants by tap water and then distilled water. Plants samples were dried to constant weight at 75ºC and their particle size were heavy clay below 0.5 mm to obtain homogenous samples.

N (nitrogen) content of samples was determined by Kjeldahl digestion and steam distillation (Lees 1971). For determination of other nutrient elements samples were digested in HNO_3 and H_2O_2 (v/v: 4/1) mixture (Cem, MarsXpress Manual). P content of the digests were colorimetrically determined (Shimadzu 1201 model UV/VIS spectrometer) according to Murphy and Riley (1962) and K (potassium), Na (sodium), Ca (calcium), Mg (magnesium), Fe (iron), Cu (copper), Mn (manganese) and Zn (zinc) contents were determined using ICP-OES (Varian, Liberty Series II) according to Kacar (1972).

After separating from the soil, the fresh roots were washed under running tap water, followed by distilled water and dried on tissue paper. Before drying, small root samples were preserved in a mixture (250:13:15) of ethanol, glacial acetic acid and formalin (Ortas et al., 2004) until the determination of mycorrhizal infection. The root clearing and staining procedure and the degree of mycorrhizal infection in the root cortex was assessed by the method of Koske and Gemma (1989). After sampling, the roots were dried and weighed for root biomass.

Basic physical and chemical properties of autoclaved soil were analyzed as follows: soil texture analysis by a hydrometer (Bouyoucos, 1951), organic matter by using Lichterfelder wet ashing (Schlichting and Blume, 1966), soil reaction and electrical conductivity by means of a combined electrode and EC meter in saturation paste, respectively (Schlichting and Blume 1966), Ca carbonate equivalent by a manometric method (Loeppert and Suarez, 1996), cation exchange capacity (CEC) by saturating sodium acetate (1M pH 8.2) and then replacing the Na with ammonium acetate (1 M pH 7.0) (U.S. Salinity Laboratory Staff, 1954), available phosphorus by Olsen method (Olsen et al., 1954), total nitrogen (N) by Bremner (1996), soil nitrate by Fabig (1979), soil ammonium by Fachgruppe Wasserchemie in der Gesellscheft Deutscher Chemiker (1983), exchangeable potassium (K) with neutral ammonium acetate by Pratt and Morse (1954), DTPA extractable microelements (Fe, Zn, Cu and Mn) by Lindsay and Norvell (1978), soil density by a picnometer by Blake and Hartge (1986b), bulk density by Blake and Hartge (1986a) and permeability by a constant head permeameter by Klute and Dirksen (1986).

The Menekşe soil series are classified as a clay textured soil (sand 257 g kg^{-1}; silt 84.8 g kg^{-1}; clay 658.2 g kg^{-1}). The pH of the soil is slightly alkaline (7.74) and there is a slight salinity problem (EC = 4.76 dSm^{-1}). The organic matter content is low (5.13 g kg^{-1}), while the CEC is 36.31 cmol kg^{-1}, density is 2.66 g cm^{-3}; bulk density is 1.519 g cm^{-3}; porosity 42.9%, and the permeability is 1.84 cm h^{-1}(medium-low). The plant nutrients of the soil are low: C 3.00 g kg^{-1}; P 3.93 mg kg^{-1}; K 155 mg kg^{-1}; NH_4 3.64 mg kg^{-1}; NO_3 2.70 mg kg^{-1}; total N 0.4 g kg^{-1}; Fe 0.305 mg kg^{-1}; Cu 0.11 mg kg^{-1}; Mn 0.172 mg kg^{-1} and Zn 0.082 mg kg^{-1}. Soil is very calcareous with 470 g kg^{-1} $CaCO_3$ content.

The data were subjected to the analysis of variance using MSTAT-C statistical analysis package (MSTATC, Michigan State University, East Lansing, MI, USA). The mean separation was made by Least Significant Difference (LSD) test at $P<0.05$. Root microphotographs were taken by the scanning electron microscope (Jeol JSM-5500LV).

RESULTS

Mycorrhizal inoculation and phosphorus and sulfur fertilizations significantly affected yield, mycorrhizal infection percent and nutrient uptake (Table 1).

Shoot and Root Yield and, Shoot Nutrient Concentration Responses to ES, P and Mycorrhizal Inoculation

Root yield by M+PoSo treatment compared to MoPoSo one significantly increased as shown in Figure 1 and, Table 2. Those results are in line with previous findings (Ortas et al., 1996; Ortas et al., 2002;

Guo et al., 2005; Karaca, 2012a; Karaca, 2013; Karaca et al., 2013) but the shoot yield was unchanged (Figure 1, and, Table 2). Nevertheless, there were no correlations all the time between the yield and shoot nutrient concentrations. In that respect, higher yields compared to lower yields can show shoot nutrient concentrations in both ways for any nutrient independently from any other one (Figure 2, 3 and, Table 2). Those results are in line with the previous findings (Menge et al., 1978; Raj et al., 1981; Yibirin et al., 1996; Karaca, 2012a; Karaca, 2012b ; Karaca et al., 2013).

MoPoS+ treatment compared to the MoPoSo one significantly decreased the shoot and root yield. The decrease of yield are not in parellel with the previous findings (McLaughlin and Holford 1982; Merrien 1987) but in accordance with the findings (Karaca, 2012b). Those yield decreases can be related to the shoot heavy metal concentrations. Thus, as presented in Figure 3, and Table 2, there were higher shoot Fe, Mn, Zn concentrations for the MoPoS+ treatment compared to the MoPoSo treatment in the non-mycorrhizal treatments. Accordingly, there may be mimic of heavy metal poisoning as is in the previous findings (Cui et al., 2004) who reported that sulfur application can increase the solubility of the nutrients for the plant uptake to result in higher growth but, in the case of heavy metal presence, the increased heavy metal in the growth conditions can cause poisining effect of heavy metals resulting in yield decrease.

M+PoS+ treatment compared to the M+PoSo one resulted in root yield decrease and no shoot yield difference. The root yield decrease and the indifference in the shoot yield are similar to the previous findings (Karaca, 2012b). The root yield decrease can be attributed to the differences in the shoot heavy metal concentrations. Thus, M+PoS+ treatment compared to M+PoSo one in the mycorrhizal treatments had higher shoot Fe concentration, but lower shoot Zn and Mn concentrations (Table 2). However, the unchanged shoot yield by M+PoS+ treatment compared to the M+PoSo one is similar to the previous findings (Hoffman et al., 1998; Guo et al., 2005).

Table 1. Analysis of variance for shoot and root yield, mycorrhizal infection and nutrient uptake in Menekşe soil.

		Shoot Dry Weight		Root Dry Weight		Root:Shoot Ratio	
Variation source	D.F.	Mean square	F value (Prob.)	Mean square	F value (Prob.)	Mean square	F value (Prob.)
Replicate	2	1757.292	1.9471 (0.1794)	1.042	0.1063	0	0.1338
Mycorrhizae(M)	1	808501.042	895.8165 (<0.0001)	9009.375	918.9891 (<0.0001)	0.001	100.4562 (<0.0001)
Sulfur(S)	1	37209.375	41.2279 (<0.0001)	1107.042	112.9223 (<0.0001)	0	5.2476 (0.038)
MxS	1	460651.042	510.3998 (<0.0001)	1335.042	136.1791 (<0.0001)	0	13.3792 (0.0026)
Phosphorus(P)	1	12463209.38	13809.1949 (<0.0001)	59700.375	6089.6557 (<0.0001)	0	22.2316 (0.0003)
MxP	1	556626.042	616.7398 (<0.0001)	4732.042	482.6855 (<0.0001)	0	10.4366 (0.006)
SxP	1	134251.042	148.7497 (<0.0001)	2223.375	226.7923 (<0.0001)	0	14.7403 (0.0018)
MxSxP	1	276276.042	306.1129 (<0.0001)	900.375	91.8415 (<0.0001)	0	0.3771
Error	14	902.53		9.804		0	
Coefficient of Variation (%)		3.00		4.37		5.21	

Continued Table 1.

		Mycorrhizal Infection		Nitrogen Uptake		Phosphorus Uptake	
Variation source	D.F.	Mean square	F value (Prob.)	Mean square	F value (Prob.)	Mean square	F value (Prob.)
Replicate	2	16.667	1	18954.167	0.0204	3457.292	1.6353 (0.2357)
Mycorrhizae(M)	1	7004.167	420.25 (<0.0001)	280576817	302.063 (<0.0001)	281666..667	130.7815 (<0.0001)
Sulfur(S)	1	204.167	12.25 (0.0035)	11070416.7	11.9182 (0.0039)	0	0
MxS	1	204.167	12.25 (0.0035)	37901066.7	40.8035 (<0.0001)	375000	174.1173 (<0.0001)
Phosphorus(P)	1	704.167	42.25 (<0.0001)	44390400	47.7898 (<0.0001)	4166666.667	1934.6369 (<0.0001)
MxP	1	704.167	42.25 (<0.0001)	35868150	38.6149 (<0.0001)	1666.667	0.7739
SxP	1	104.167	6.25 (0.0255)	1892816.67	2.0378 (0.1754)	26666.667	12.3817 (0.0034)
MxSxP	1	104.167	6.25 (0.0255)	61056600	65.7322 (<0.0001)	735000	341.27 (<0.0001)
Error	14	16.667		928868.452		2153.72	
Coefficient of Variation (%)		23.9		2.00		2.14	

Continued Table 1.

		Potassium Uptake		Calcium Uptake		Magnesium Uptake	
Variation source	D.F.	Mean square	F value (Prob.)	Mean square	F value (Prob.)	Mean square	F value (Prob.)
Replicate	2	26852.478	0.1226	21625.452	0.6561	9711.354	0.3387
Mycorrhizae(M)	1	10359446.4	47.3115 (<0.0001)	3674385.81	111.4737 (<0.0001)	571836.063	19.9455 (0.0005)
Sulfur(S)	1	6205631.71	28.3411 (0.0001)	26606.772	0.8072	646422.663	22.5471 (0.0003)
MxS	1	5523059.12	25.2238 (0.0002)	2401918.7	72.8695 (<0.0001)	37651.728	1.3133 (0.271)
Phosphorus(P)	1	49791696	227.3984 (<0.0001)	2155622.63	65.3974 (<0.0001)	2697018.822	94.0714 (<0.0001)
MxP	1	611477.546	2.7926 (0.1169)	538950.364	16.3507 (0.0012)	29934.448	1.0441 (0.3242)
SxP	1	4662343.89	21.2929 (0.0004)	1039542.71	31.5377 (0.0001)	19482.591	0.6795
MxSxP	1	26710.76	0.122	14974.986	0.4543	358975.008	12.521 (0.0033)
Error	14	218962.341		32961.909		28669.917	
Coefficient of Variation (%)		2.54		2.63		2.47	

MoP+So treatment compared to MoPoSo treatment significantly increased the shoot and root yield in the non-mycorrhizal treatments (Table 2) being in line with the findings (Ortas et al., 1996; Karaca, 2012a). Those yield increases can be related to the low P content of soil. So, it could be expected that P fertilization in soils low in P content can increase the yield. Interestingly, the increase in question in both shoot and root yield by M+P+So treatment in the mycorrhizal treatments compared to the MoP+So one in the non-mycorrhizal treatments was higher indicating the synergism between mycorrhizae and P being not consistent with the findings (Baylis, 1967; Mosse, 1967; Karaca et al. 2013).

Continued Table 1.

		Iron Uptake		Zinc Uptake		Copper Uptake	
Variation source	D.F.	Mean square	F value (Prob.)	Mean square	F value (Prob.)	Mean square	F value (Prob.)
Replicate	2	49.115	2.5174 (0.1164)	0.022	0.0034	0.167	1.3207 (0.2982)
Mycorrhizae(M)	1	3551.938	182.0554 (<0.0001)	13.261	2.0015 (0.179)	30.917	244.4604 (<0.0001)
Sulfur(S)	1	571.448	29.2897 (0.0001)	249.099	37.597 (<0.0001)	4.753	37.5782 (<0.0001)
MxS	1	61.216	3.1376 (0.0983)	75.828	11.4449 (0.0045)	19.189	151.7237 (<0.0001)
Phosphorus(P)	1	11.551	0.592	1594.792	240.7046 (<0.0001)	230.888	1825.605 (<0.0001)
MxP	1	0.377	0.0193	48.45	7.3127 (0.0171)	0.047	0.3702
SxP	1	264.87	13.576 (0.0025)	26.418	3.9873 (0.0657)	16.302	128.8982 (<0.0001)
MxSxP	1	379.135	19.4327 (0.0006)	672.465	101.4963 (<0.0001)	1.5	11.8603 (0.004)
Error	14	19.51		6.626		0.126	
Coefficient of Variation (%)		2.39		2.60		1.79	

Continued Table 1.

		Manganese Uptake		Sodium Uptake	
Variation source	D.F.	Mean square	F value (Prob.)	Mean square	F value (Prob.)
Replicate	2	24.931	1.8238 (0.1977)	1284.838	0.1587
Mycorrhizae(M)	1	18122.512	1325.7056 (<0.0001)	542589.095	67.0398 (<0.0001)
Sulfur(S)	1	304.451	22.2714 (0.0003)	116499.421	14.3941 (0.002)
MxS	1	1944	142.2083 (<0.0001)	447272.348	55.2629 (<0.0001)
Phosphorus(P)	1	3804.194	278.286 (<0.0001)	3814155.254	471.2597 (<0.0001)
MxP	1	4082.042	298.6112 (<0.0001)	6301.152	0.7785
SxP	1	347.321	25.4073 (0.0002)	203205.882	25.1072 (0.0002)
MxSxP	1	944.764	69.1118 (<0.0001)	16114.947	1.9911 (0.1801)
Error	14	13.67		8093.532	
Coefficient of Variation (%)		3.26		3.63	

Table 2. Response of pepper to mycorrhizal inoculation, fertilization with elemental sulfur and phosphorus in Menekşe soil.

				Menekşe soil			
Treatment	Shoot DW (mg)	Root DW (mg)	R/S	Mycorrhizal infection (%)	N content (mg/kg)	P content (mg/kg)	K content (mg/kg)
MoPoSo	315.00e	20.67f	0.07	0.00d	49606.67c	1566.67g	16052.81
MoP+So	1516.67c	85.33d	0.06	0.00d	52510.00ab	2800.00b	19429.09
MoPoS+	181.67f	12.33g	0.07	0.00d	53390.00a	1733.33f	16925.15
MoP+S+	1253.33d	91.00c	0.07	0.00d	51036.67bc	2133.33d	18671.86
M+PoSo	315.00e	28.67e	0.09	43.33a	46026.67d	1866.67e	16021.41
M+P+So	1696.67b	125.00b	0.07	13.33c	47440.00d	2433.33c	20169.61
M+PoS+	306.67e	25.67ef	0.08	46.67a	38403.00e	1833.33e	18946.06
M+P+S+	2416.67a	185.00a	0.08	33.33b	47320.00d	2966.67a	21197.80
LSD	52.60	5.483	0.0554	7.149	1688	81.27	819.5

* different letter implies significant differences in the same column.

Continued Table 2.

				Menekşe Soil			
Treatment	Ca content (mg/kg)	Mg content (mg/kg)	Fe content (mg/kg)	Zn content (mg/kg)	Cu content (mg/kg)	Mn content (mg/kg)	Na content (mg/kg)
MoPoSo	6644.00	6737.13b	183.62c	103.57c	25.99a	92.55c	3314.71
MoP+So	7076.90	6438.90c	197.08b	98.60d	18.72d	163.97a	2352.79
MoPoS+	5478.50	7287.73a	211.17a	109.17b	22.16b	137.83b	2770.13
MoP+S+	6843.80	6386.33c	195.44b	87.22e	17.19e	168.93a	2072.63
M+PoSo	7043.60	7281.87a	170.68de	119.07a	25.52b	94.22c	2760.38
M+P+So	6977.00	6353.17c	167.74e	87.24e	14.08f	88.38cd	1759.63
M+PoS+	7243.43	7501.70a	175.94cd	96.39d	21.27c	78.40e	2658.21
M+P+S+	7909.40	6948.23b	175.61d	89.93e	17.12e	82.44de	2129.17
LSD	317.9	296.5	7.735	4.508	0.6216	6.475	157.5

* different letter implies significant differences in the same column.

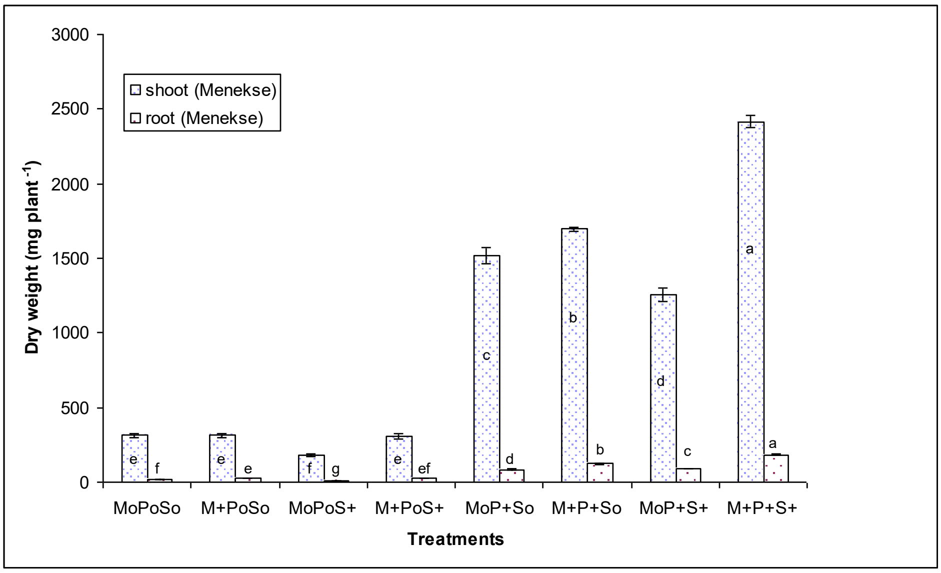

Figure 1. Pepper shoot and root dry weight following mycorrhizal inoculation and P and ES fertilization in Menekşe soil. Different letters indicate significant difference between the treatments. Error bars indicate standard deviation.

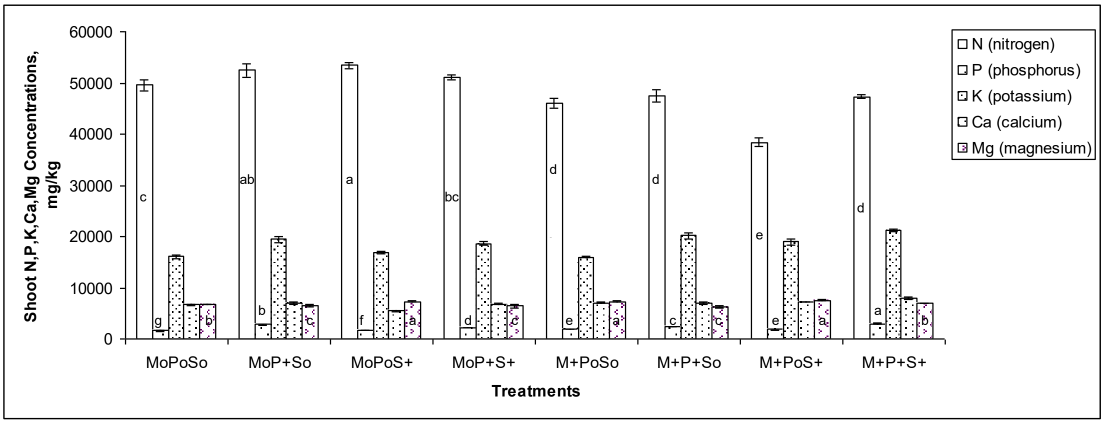

Figure 2. Pepper N,P,K,Ca,Mg content following mycorrhizal inoculation and P and ES fertilization in Menekşe soil. Different letters indicate significant difference between the treatments. Error bars indicate standard deviation.

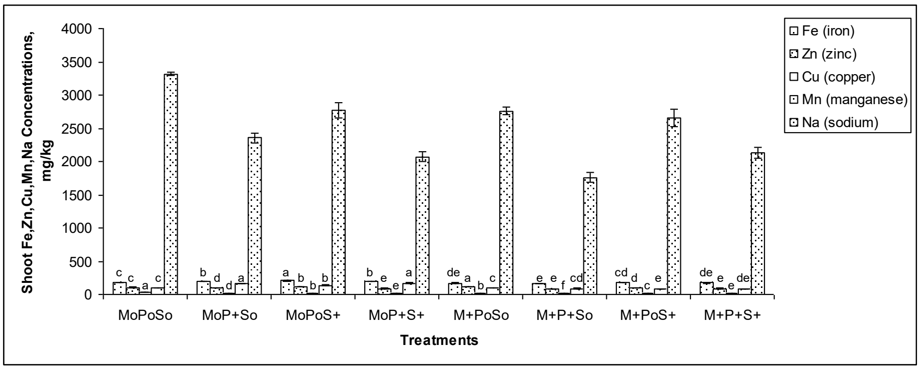

Figure 3. Pepper Fe,Zn,Cu,Mn,Na content following mycorrhizal inoculation and P and ES fertilization in Menekşe soil. Different letters indicate significant difference between the treatments. Error bars indicate standard deviation.

MoP+S+ treatment compared to MoP+So one significantly decreased the shoot yield whereas the root yield significantly increased in the non- mycorrhizal treatments. The shoot yield decrease can be attributed to the increased root yield with the differences in the shoot nutrient concentrations. With respect to that, while the shoot Mn, Mg and Fe concentrations were unchanged, the shoot N, P, Zn and Cu concentrations were significantly lower for M_0 P+S+ treatment compared to M_0 P+S_0 one in the non-mycorrhizal treatments as shown in Figure 2, 3 and Table 2.

Both shoot and root yield increases were significant in the mycorrhizal treatments for M+P+S+ treatment compared to M+P+So indicating the further synergism among mycorrhizae, ES and P compared to the synergism between mycorrhizae and phosphorus in the clay soil growth conditions. Those yield increases can also be related to the differences in the shoot nutrient concentrations, too. In that respect, the shoot P, Mg, Fe and Cu concentrations significantly increased while the shoot Mn concentration significantly decreased for the M+P+S+ treatment compared to the M+P+So one with the unchanged shoot Zn and N concentrations in the mycorrhizal treatments. Moreover, M+P+S+ treatment in the mycorrhizal treatments resulted in the highest yield where the highest shoot nutrient concentration was P among the all treatments. On the other hand, those differences in the yield and shoot nutrient concentrations are reciprocally culminated in for the response to the root morphological changes (Figure 4).

Those results above indicate that different treatments in clay soil growth conditions affect the efficient use of nutrients and mycorrhizae with the subsequent root morphological changes in plant resulting in those yield differences.

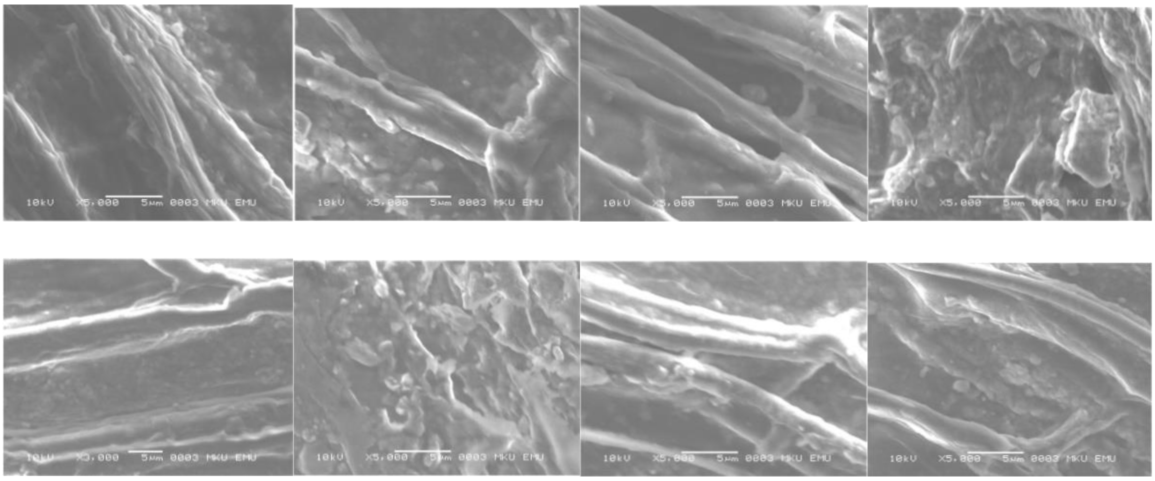

Figure 4. Root morphologies of Menekșe soil from the left to the right for the response of the treatments of MoPoSo, MoPoS+, MoP+So, MoP+S+ above, and M+PoSo, M+PoS+, M+P+So, M+P+S+ below, respectively.

Root Mycorrhizal Infection Responses to ES, P and Mycorrhizal Inoculation

The highest root mycorrhizal infection levels in the mycorrhizal treatments by M+PoSo and M+P_0 S+ treatments without P fertilization were obtained. However, M+P+So or M+P+S+ treatment compared to M+PoSo and M+P_0S+ ones in the mycorrhizal treatments significantly decreased the root mycorrhizal infection level. Those findings are in line with the previous findings (Baylis, 1967;

Mosse, 1967; Karaca, 2012a) who reported that mycorrhizal infections tend to stop in soils containing or given high P. However, M+PoS+ treatment compared to M+PoSo one in the mycorrhizal treatments did not affect the root mycorrhizal infection level as shown in Figure 5. Those findings are not consistent with the previous findings (Diaz et al., 1996) who reported that a slight reduction on percentage of mycorrhizal colonization was noted by SO_2 treatment. On the other hand, the ES addition compensated the decreasing effect of P fertilization to some extent in the root mycorrhizal infection level being in line with the previous findings (Karaca, 2012a). Moreover, M+P+S+ treatment compared to the M+P+So treatment in the mycorrhizal treatments resulted in the highest root and shoot yields among the all treatments (Table 2). This clearly shows that ES increases the efficient work of mycorrhizae beside compensation of the decreasing effect of P in the root mycorrhizal infection level. Those changing root infection levels can be related to the different treatments in the plant growth conditions.

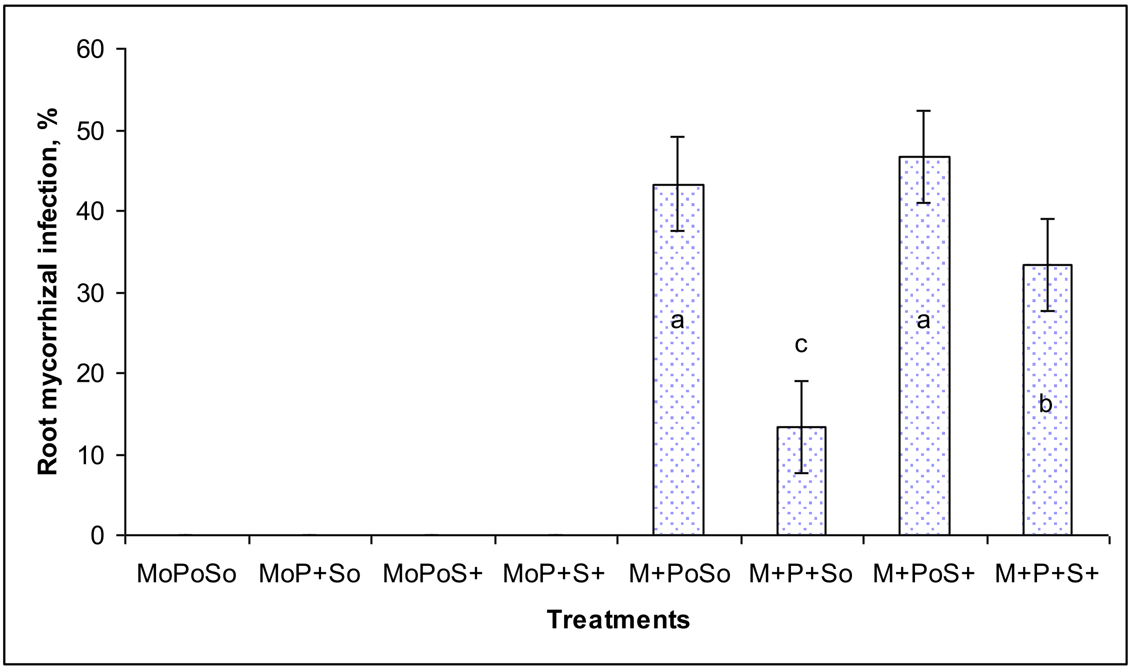

Figure 5. Pepper mycorrhizal infection percent following mycorrhizal inoculation and P and ES fertilization in Menekşe soil. Different letters indicate significant difference between the treatments. Error bars indicate standard deviation.

Root to Shoot ratio

M+PoSo treatment compared to the MoPoSo one did not affect the root to shoot ratio. Similarly, the root to shoot ratio were statistically unchanged among the all treatments including mycorrhizal and non-mycorrhizal ones. Those indifferences in the root to shoot ratio are similar to the previous findings (Ortas et al., 2002; Karaca, 2012a). Eventhough, statistically insignificant fluctuating root to shoot ratios among the treatments came out (Table 1), there were no correlations all the time between the yield level and root to shoot ratio for the different treatments in the growth medium conditions. Accordingly, higher yield compared to lower yield may have the root to shoot ratio trend in the both directions as presented in Figure 6. Those findings are similar to the findings (Karaca, 2012a). Those ratios may lend support to the hypothesis (Romero et al., 1996) who proposed that there may be an optimum root to shoot ratio for plant growth.

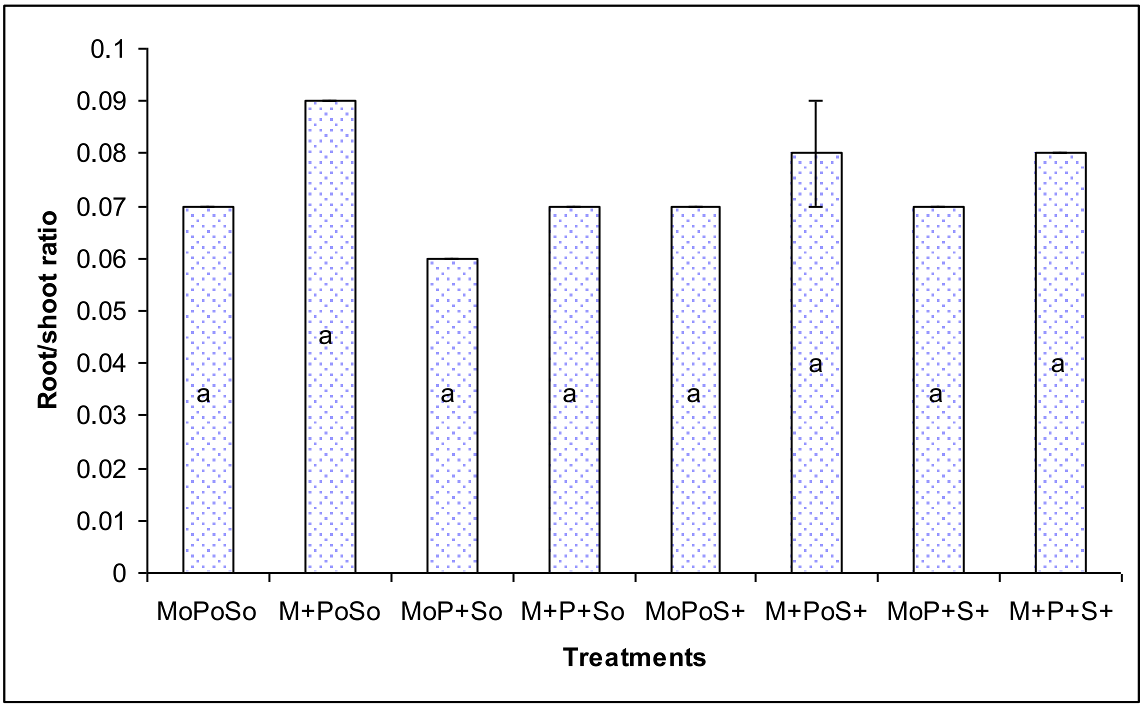

Figure 6. Pepper root to shoot ratio (dry weight) following mycorrhizal inoculation and P and ES fertilization in Menekşe soil. Different letters indicate significant difference between the treatments. Error bars indicate standard deviation.

DISCUSSION

Mycorrhizal inoculation alone compared to control treatment resulted in higher root yield with unchanged shoot yield. That indicates that the root growth has the priority for plant growth to be able to create investment potential for the future shoot growth depending upon the growth period of plant. Concomitantly, the shoot N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and Na concentrations were diluted, accumulated or unchanged for any nutrient independent from each other as the yield response. However, P fertilization and mycorrhizal inoculation in combination compared to the P fertilization alone created mutual stimulative effect resulting in the significantly increased shoot and root yield. That shows that the growth of pepper in the clay soil growth conditions is vigorous as a response to the P fertilization in the mycorrhizal treatments. On the other hand, the increase of shoot and root yield by the P fertilization in the mycorrhizal treatments increased significantly farther by ES and P fertilization in combination resulting in the highest yields among the all treatments. In relation to that, the changed shoot nutrient concentrations in both direction for any nutrient independent from any other one seems to be also related to the subsequent yield differences in the plant growth conditions. Consequently, soil type, mycorrhizae inoculation, treatment and plant growth period can be involved in creating the further yield differences. It can be emphasized that fertilization regulations in clay soil growth conditions can be related to increase the efficient work of mycorrhizae for the vigorous growth of pepper to some great extent.

The increased efficient work of mycorrhizae resulting in the highest shoot and root yield in the clay soil growth conditions by ES and P fertilization in combination for pepper may shed light to prevent yield losses resulting from heavy metal accumulation in plant tissues to obtain higher yield in agriculture. Accordingly, regulation of fertilizer forms and doses can lead to contribution of the plant production system causing the efficient work of mycorrhizae.

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Boron content of wide soil groups of Siverek (Şanlıurfa) region

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Abstract

In the study, it was aimed to determine the boron content of the wide soil groups in Siverek county of Şanlıurfa province and to determine relations with some properties of the soil. For this purpose, a total of 76 soil samples were taken from two different depths (0-20 and 20-40 cm) and 38 points, representing the wide soil groups of Siverek county of Şanlıurfa. Texture, pH, salt, lime, organic matter and available boron contents of the soils were determined in the samples. The results of the research show that the pH contents of soils is between 6.91-7.98; salt content is between 0.02-0.13%; clay content is between 24.32-67.76%; sand content is between 2.40-62.96%; silt content is between 6.00-68.72%; lime content is between 0.38-14.55%; organic matter content is between 1.11-3.35% and boron content of them is between 0.01-1.99 mg/kg. The obtainable boron content of the wide soil groups of Siverek county of Şanlıurfa province was found to be 65.38% too little, 26.32% little, 7.90% adequate at the depth of 0-20 cm, whereas it was found to be 81.58% too little, 15.79% little and 2.63% sufficient at 20-40 cm depth. It was determined that there is a positive significant relationship between the obtainable boron content of soil and pH and lime contents. In addition, significant positive relationships between pH content and silt and lime were determined. Not only a negative significant relation between clay content and silt content of soils was determined, but negatively significant relations between sand content and silt and organic matter were determined, as well. At the same time, positive correlations were determined between the lime content of the soils and the organic matter.

Key words: Boron content, wide soil groups, soil properties

INTRODUCTION

Very few and limited levels of agricultural areas and agricultural inputs on earth increase the value of agricultural regions. The chemical, physical and biological properties of soils have an important place directly and indirectly on the amount of crops to be obtained from agricultural land. In order to obtain the best results from agricultural production, the well-known soil texture and characteristics is a very important factor affecting the agricultural production process (Karaduman and Çimrin 2016).

The desired level of plant nutrients in the soil is closely related to different environmental factors, including climatic conditions, together with soil factors such as pH, salt, body, organic matter, lime and KDK (Özyazıcı et al. 2013, Sevindik et al. 2017). It is known that the amount of boron in the soil affects the factors such as the type of plant, the amount of organic ions, the temperature of the soil, as well as the variety of the plant and the pH of the soil (Şimşek et al. 2003).

Boron deficiency is not as little as it is seen in more than 80 countries around the world (Shorrocks 1977). Lehto et al. (2010); Bell and Dell (2008), according to the area of the precipitation of sandy soils and alkaline pH soil is very common in the lack of boron. In addition to this, the lack of good soil management and fertilization is the inevitable result when the deficiency of plant nutrient elements in the soil increases with the advancement of agricultural activities. On the other hand, boron toxicity is a serious problem in arid regions where predominantly trees are not dominated in many parts of the world, and the window between deficiency and toxicity is generally known to be very narrow (Lehto et al. 2010). In other words, while the boron, which is found in very low amounts in some soils, has a deficiency for plants as a nutrient, it can be reached to toxic level for the plants by giving too much. Boron element in the production of pectic cells in the cell wall in plant production has been suggested to play an important role (Lehto et al. 2010), although many studies on the effect in the plant in general, the plant functions are not understood clearly (Demirtaş 2005).

Yalçın and Çimrin (2017) aimed to determine boron content of meadow and pasture soils in Kırıkhan-Reyhanlı region of Hatay province and to determine their relationships with some properties of soil. According to the results of their work; pH contents of soils 6.85-8.16; salt content 0.01-0.21%; clay contents 4.60-65.30%; sand contents% 8.70-85.40; silt contents 8.00-58.00%; lime content 3.40-53.95%; organic matter contents were found between 0.29-5.52% and the contents of boron were found between 0.00-1.31 ppm. At the same time, in terms of boron content of meadow pasture soils at a depth of 0-20 cm 70% very little, 27.50% less, 2.50% sufficient level, 20-40 cm depth 72.50% very little, 17.50% They found that less than 10% of them have sufficient levels. In addition, the negative relationship between the boron and sand contents of the soil is determined while the important relationship between the contents of salt, clay, silt and lime content of the boron. Özyazıcı et al. (2013) aimed to reveal the physical and chemical properties of the alfalfa cultivated soil and the problems related to plant nutrition in Artvin region. According to the results of the study; the soil is generally of clayey loam, sand, sandy loam and sandy loam, 55.13% of them have neutral reactions, 58.97% of them have low calciferous and no salinity problems. In addition, it was determined that 46.16% of the soil has the deficiency of extractable boron and 16.67% of the soil has the deficiency of the extractable Mn. Taban et al. (2004), who determined the fertility status and nutritional problems of the soil made of garlic cultivation in the Kastamonu Taşköprü region, found within the results of their study that the soil in the region has no issues of salinity; in 85.00% of the soils KDK had> 25 mg/kg soil, and in 55.00% of the soils organic matter was insufficient, in 45.00% of the medium and 67.50% of it was insufficient in terms of boron. Budak and Günal (2015) aimed to map the distance-dependent variation of the available boron concentration in the salt and alkaline soils in the Bor district of Niğde province by geostatistical methods. As a result of the study, the boron concentration of the soil varied between 1.41 and 97.84 mg/kg and the average concentration was 47.76 mg/kg. They found that in a large part of the study area soils the boron concentration is over 5 mg/kg, which is the toxic limit for most crops.

In this study, the sludge contents of wide soil groups in Siverek district of Şanlıurfa province will be investigated and their relations with some soil properties will be investigated. As a result, it was aimed to contribute to the yield and quality of agricultural production in wide soil groups in Siverek district.

MATERIAL AND METHOD

A total of 76 soil samples from 38 points, 0-20 and 20-40 cm depths were taken in a manner to represent the region in the area of Siverek county of Şanlıurfa province in accordance with the procedure (Figure 1; Table 1). The soil samples brought to the laboratory on the same day were dried in the shade and dried by a 2 mm sieve.

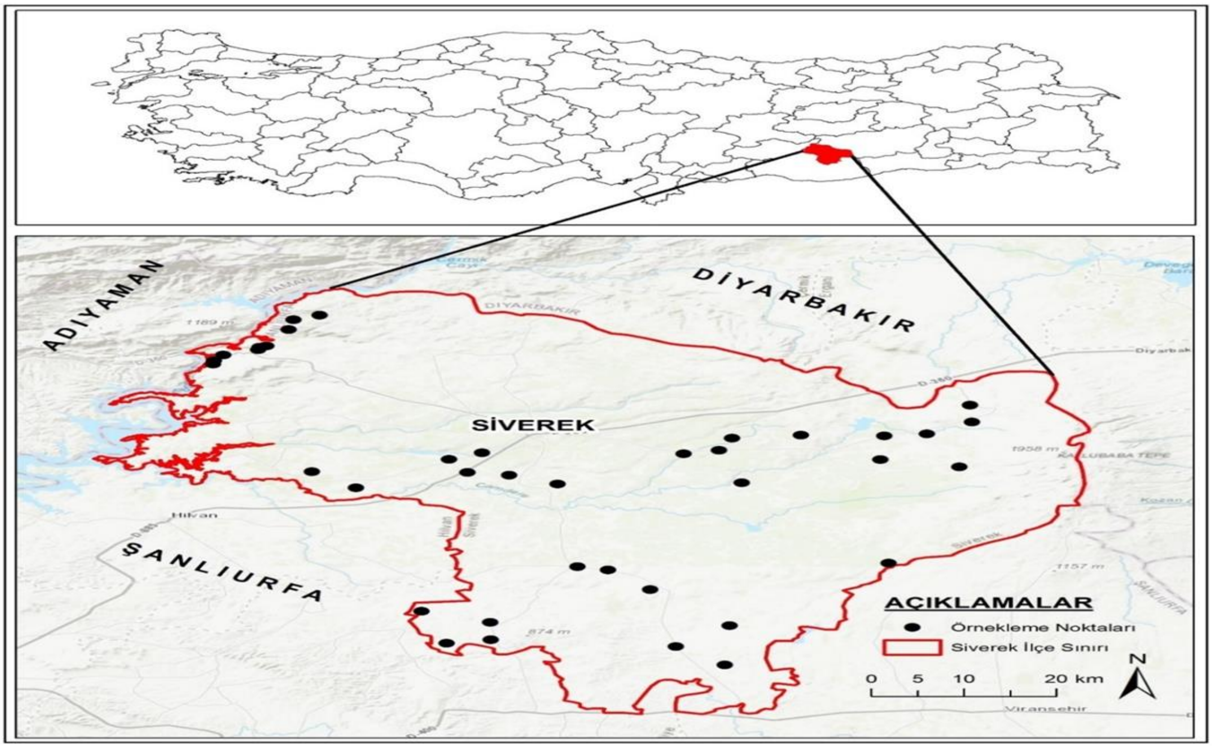


Figure 1. Representation of soil samples taken on Siverek district map.

Table 1. Soil samples were taken

Soil Number	Sample Place	Soil Class (IUSS WRB Working Group 2015)	Soil Number	Sample Place	Soil Class (IUSS WRB Working Group 2015)
1	Gözelek	Cambisol	20	Aşağıkarabahçe	Vertisol
2	Karakoyun	Cambisol	21	Sabanlı-1	Cambisol
3	Çeltik	Cambisol	22	Karakeçi	Cambisol
4	Çanakçı	Cambisol	23	Turna	Cambisol
5	Yücelen-1	Cambisol	24	Başbuk-1	Calcisol
6	Yücelen-2	Cambisol	25	Başbuk-2	Calcisol
7	Ediz	Cambisol	26	Alayurt	Cambisol
8	Çatlı	Cambisol	27	Aşağıkaracaören	Cambisol
9	Erkonağı	Cambisol	28	Karadibek	Cambisol
10	Gedik	Cambisol	29	Sabanlı-2	Vertisol
11	Gazi	Cambisol	30	Ergen-1	Cambisol
12	Eğriçay	Cambisol	31	Narlıkaya-1	Cambisol
13	Savucak	Vertisol	32	Narlıkaya-2	Cambisol
14	Karacadağ-1	Vertisol	33	Narlıkaya-3	Cambisol
15	Sumaklı	Vertisol	34	Ergen-2	Cambisol
16	Keçikıran	Cambisol	35	Ergen-3	Cambisol
17	Karacadağ-2	Cambisol	36	Kayalı-1	Cambisol
18	Altınahır	Cambisol	37	Kayalı-2	Cambisol
19	Altınlı	Cambisol	38	Kayalı-3	Cambisol

Methods

The total soluble salt content of the soils was measured in the electrical conductivity instrument in the saturation sludge extract and the pH values in the pH meter instrument (Richards 1954). Lime ($CaCO_3$) contents were measured with Scheibler calcimetres (Allison and Moode 1965). It was determined by hydrometer method (Bouyoucos 1952). The organic matter contents of soils were determined by the Walkley-Black method modified by Jackson (1960). Available B analysis of the soils was determined using ICP-OES device in strainer obtained using 0.01 M mannitol + 0.01 M $CaCl_2$ extract solution (Cartwright et al. 1983). Correlation and regression analysis of soil properties and available boron contents were done by SPSS 17 statistical program (Düzgüneş et al. 1987).

RESULTS AND DISCUSSION

Some Physical and Chemical Properties of Soils

Some physical and chemical properties of soil properties used in the research are given in Table 2. The pH content of the study soils was 6.91 in the samples and the highest pH content was 7.98. The average pH content of the soil samples of 0-20 cm depth was 7.54, whereas the samples with a depth of 20-40 cm were 7.57 and it was 7.55 in two depths. According to Ülgen and Yurtsever (1995), the pH of the soil samples ranged from neutral to slightly alkaline, whereas 42.10% of the soils were neutral and 57.90% were slightly alkaline (Table 2). Saraçoğlu et al. (2014), who work in the same land, reported similar results in the study of some of the soil and plant nutrient contents of the territory of Halfeti district of Şanlıurfa province.

The salt content of the soil in the study area was 0.02%, the highest salt content was 0.13%. The average of 0 to 20 cm of soil samples was 0.06%, while the samples with a depth of 20-40 cm were 0.07% and the mean of both depths was 0.07%. According to the limit values reported by Richards 1954, the total salt content of the soil samples was determined as salt-free (Table 2). In the same region, the general nutrition status of some olive orchards located in the center and districts of Şanlıurfa was investigated by Söylemez et al. (2017) who also reported that all of the % salt contents of soils were in the salt-free class.

The clay, sand and silt quantities of the soil of the major soil groups in Siverek district were at least 24.32%, 2.40% and 6.00% respectively, while the highest clay, sand and silt contents were 67.76%, 62.96% and 68.72%, respectively. The average clay, sand and silt contents of the soils at 0-20 cm depth were 34.61%, 21.08% and 44.31%, while the mean values were 33.68%, 23.07% and 43.25% for samples with a depth of 20-40 cm, and 34.15%, 22.08% and 43.78%, respectively. The land of Siverek district As seen in Table 2, 51.32% of silty clay, 10.53% clay, 10.53% clayey loam, 2.63% loamy 5.26% sandy clay, 9.22% silty loam, 3.94% of the silty clay and 6.75% of the sandy clay was entered into 8 different class of textures. Saraçoğlu et al. (2014), who work in the same land, reported similar results in the study of some of the soil and plant nutrient contents of the land of Şanlıurfa- Halfeti province.

Texture, pH, salt, lime, organic matter

The lime content of the research lands was 0.38% in the samples while the highest lime content was determined as 14.55%. The average lime content of the 0-20 cm depth samples was 3.64% in the depths of 20-40 cm and 3.87% in the depths of the soil. According to the classification of soil samples by Ülgen and Yurtsever (1995), although the contents of the lime ranged between low calcareous and medium calcareous, 2.64% of the soils were found to be low calcareous, 73.68% were calcareous and 23.68% were medium calcareous (Table 2). Saraçoğlu et al. (2014) The lime content of the soils of Halfeti district of Şanlıurfa province has changed between 0.38% and 33.80%, 4.00% of the soils are less calcareous, 48.00% is calcareous, 17.00% is medium, 9.00% is more than 22.00%. reported that they were too calcareous.

Table 2. Some physical and chemical properties and boron contents of wide soil groups in Şanlıurfa-Siverek Province.

Soil Number	Depth	pH	Salt %	Clay %	Sand %	Silt %	Texture class	Lime %	O.M. %	B mg/kg
1	0-20	7.28	0.04	24.32	21.68	54.00	SiL	1.47	1.90	0.06
	20-40	7.29	0.05	26.32	23.68	50.00	SiL	1.47	1.88	0.24
2	0-20	7.67	0.08	35.04	9.68	55.28	SiCL	2.71	1.95	0.15
	20-40	7.74	0.08	31.76	15.68	52.56	SiCL	2.69	1.66	0.29
3	0-20	7.74	0.06	30.32	13.68	56.00	SiCL	1.31	1.53	0.63
	20-40	7.79	0.07	30.32	14.96	54.72	SiCL	1.54	1.55	0.23
4	0-20	7.39	0.10	32.32	11.68	56.00	SiCL	1.31	2.11	0.39
	20-40	7.42	0.10	32.32	14.96	52.72	SiCL	1.69	1.99	0.39
5	0-20	7.44	0.10	34.32	7.68	58.00	SiCL	1.46	1.90	0.06
	20-40	7.40	0.10	32.32	10.96	56.72	SiCL	1.46	1.66	0.46
6	0-20	7.65	0.08	27.04	19.68	53.28	SiCL	3.16	2.27	0.07
	20-40	7.58	0.10	30.32	17.68	52.00	SiCL	1.54	2.05	0.28
7	0-20	7.74	0.08	30.32	13.68	56.00	SiCL	1.54	1.85	0.02
	20-40	7.80	0.08	31.04	20.40	48.56	CL	1.92	1.49	0.13
8	0-20	7.57	0.08	32.32	22.96	44.72	CL	4.39	3.33	0.01
	20-40	7.55	0.08	32.32	12.40	55.28	SiCL	2.69	3.26	0.18
9	0-20	7.88	0.05	26.32	20.40	53.28	SiL	10.47	1.64	0.11
	20-40	7.85	0.05	30.32	22.96	46.72	CL	10.16	1.60	0.81
10	0-20	7.48	0.09	34.32	12.40	53.28	SiCL	0.38	1.80	0.04
	20-40	7.52	0.10	32.32	12.96	54.72	SiCL	1.46	1.55	0.18
11	0-20	7.41	0.07	36.32	8.40	55.28	SiCL	1.15	1.58	0.65
	20-40	7.48	0.07	40.32	8.96	50.72	SiC	1.31	1.38	0.10
12	0-20	7.36	0.06	30.32	12.40	57.28	SiCL	1.15	2.51	0.01
	20-40	7.41	0.07	34.32	12.96	52.72	SiCL	1.15	2.41	0.12
13	0-20	7.11	0.06	67.76	2.40	29.84	C	1.08	1.85	0.52
	20-40	7.07	0.06	46.32	8.96	44.72	SiC	1.31	1.83	0.25
14	0-20	7.06	0.06	65.76	8.40	25.84	C	1.15	2.17	0.08
	20-40	7.10	0.06	64.32	11.68	24.00	C	1.23	1.88	0.18
15	0-20	7.27	0.07	52.32	14.40	33.28	C	1.00	1.58	0.41
	20-40	7.36	0.07	42.32	14.40	43.28	SiC	1.39	1.49	0.06
16	0-20	7.67	0.08	30.32	12.40	57.28	SiCL	3.52	1.27	0.03
	20-40	7.73	0.08	32.32	15.68	52.00	SiCL	4.52	1.11	0.81
17	0-20	7.73	0.07	30.32	16.40	53.28	SiCL	2.37	1.98	0.12
	20-40	7.75	0.07	26.32	21.68	52.00	SiL	2.68	1.69	0.27
18	0-20	7.78	0.06	34.32	8.40	57.28	SiCL	3.16	1.98	0.06
	20-40	7.82	0.07	28.32	13.68	58.00	SiCL	3.69	1.88	0.16
19	0-20	7.75	0.07	31.04	14.40	54.56	SiCL	1.46	1.53	0.89
	20-40	7.71	0.07	30.32	17.68	52.00	SiCL	1.77	2.10	0.11
20	0-20	6.98	0.04	48.32	18.40	33.28	C	8.74	2.17	0.01
	20-40	6.91	0.04	44.32	15.68	40.00	C	9.39	2.16	0.36

Table 2. (continued)

Soil Number	Depth	pH	Salt %	Clay %	Sand %	Silt %	Texture class	Lime %	O.M. %	B mg/kg
21	0-20	7.82	0.06	30.32	16.40	53.28	SiCL	6.23	2.01	1.08
	20-40	7.85	0.06	30.32	15.68	54.00	SiCL	6.16	1.74	0.95
22	0-20	7.37	0.09	24.32	22.40	53.28	SiL	4.23	2.48	0.06
	20-40	7.39	0.08	30.32	19.68	50.00	SiCL	4.62	2.43	0.17
23	0-20	7.51	0.10	28.32	16.40	55.28	SiCL	2.31	2.01	0.43
	20-40	7.54	0.12	32.32	13.68	54.00	SiCL	1.62	2.02	0.32
24	0-20	7.65	0.08	30.32	14.40	55.28	SiCL	13.86	2.43	0.13
	20-40	7.71	0.08	28.32	14.96	56.72	SiCL	14.55	2.38	0.23
25	0-20	7.76	0.04	36.32	12.96	50.72	SiCL	7.77	2.56	0.10
	20-40	7.79	0.04	36.32	13.68	50.00	SiCL	8.47	2.35	0.15
26	0-20	7.81	0.05	28.32	2.96	68.72	SiCL	1.92	1.74	0.23
	20-40	7.88	0.04	23.60	10.96	65.44	SiL	2.69	1.77	0.10
27	0-20	7.77	0.06	28.32	13.68	58.00	SiCL	2.31	1.93	1.99
	20-40	7.74	0.06	30.32	14.96	54.72	SiCL	2.69	1.94	0.96
28	0-20	7.76	0.05	30.32	17.68	52.00	SiCL	8.31	2.38	1.13
	20-40	7.82	0.06	28.32	22.96	48.72	SiCL	8.39	2.43	0.23
29	0-20	7.49	0.12	46.32	21.68	32.00	C	3.46	3.35	0.15
	20-40	7.57	0.13	50.32	14.96	34.72	C	4.16	3.15	0.21
30	0-20	7.30	0.05	26.32	11.68	62.00	SiL	1.08	2.54	0.01
	20-40	7.39	0.05	27.76	30.96	41.28	SiCL	1.54	2.21	0.01
31	0-20	7.06	0.02	34.32	55.68	10.00	SCL	1.15	1.56	0.01
	20-40	7.09	0.02	34.32	54.24	11.44	SCL	0.85	1.44	0.04
32	0-20	7.22	0.02	37.04	47.68	15.28	SC	1.15	1.37	0.21
	20-40	7.31	0.02	37.04	48.24	14.72	SC	1.62	1.16	0.09
33	0-20	7.94	0.03	26.32	31.68	42.00	L	8.47	1.53	0.75
	20-40	7.98	0.03	28.32	42.24	29.44	CL	8.47	1.58	0.93
34	0-20	7.97	0.04	32.32	42.96	24.72	CL	7.54	1.43	0.64
	20-40	7.95	0.04	26.32	44.96	28.72	L	8.01	1.27	0.30
35	0-20	7.78	0.04	37.76	37.68	24.56	CL	11.55	2.98	0.79
	20-40	7.86	0.04	36.32	36.24	27.44	CL	12.55	3.10	1.82
36	0-20	7.32	0.02	38.32	45.68	16.00	CL	1.00	1.21	0.49
	20-40	7.41	0.02	32.32	54.96	12.72	SCL	1.31	1.13	0.14
37	0-20	7.47	0.02	30.32	62.24	7.44	SCL	1.54	1.48	0.33
	20-40	7.52	0.02	28.32	62.96	8.72	SCL	1.54	1.38	0.03
38	0-20	7.43	0.03	36.32	57.68	6.00	SC	1.54	1.74	0.22
	20-40	7.46	0.03	40.32	52.24	7.44	SC	1.54	1.60	0.06
Min		**6.91**	**0.02**	**24.32**	**2.40**	**6.00**		**0.38**	**1.11**	**0.01**
Max		**7.98**	**0.13**	**67.76**	**62.96**	**68.72**		**14.55**	**3.35**	**1.99**
Ave.	**0-20**	**7.54**	**0.06**	**34.61**	**21.08**	**44.31**		**3.64**	**1.99**	**0.34**
Ave.	**20-40**	**7.57**	**0.07**	**33.68**	**23.07**	**43.25**		**3.84**	**1.89**	**0.33**
	Ave.	**7.55**	**0.07**	**34.15**	**22.08**	**43.78**		**3.74**	**1.94**	**0.34**

The organic matter content of the soils was 1.11% and the highest organic matter was 3.35%. The average organic matter of the samples in the 0-20 cm depth of soil was 1.99% and 1.89% in the samples with a depth of 20-40 cm and 1.94% in two depths. According to Ülgen and Yurtsever (1995) classification of soil samples, although organic matter varied between very low and medium level, 63.16% of the soils were less, 30.26% were medium and 6.58% were good organic matter (Table 2). The aim of the study was to determine the general nutritional status of some olive orchards in the center and districts of Şanlıurfa in the same region. Söylemez et al. (2017) The organic matter contents of the lands of Şanlıurfa have been reported to be between 0.37% and 2.32% and, 88.24% of the soils have low organic matter content.

The lowest boron concentration was 0.01 mg/kg and the highest boron concentration was 1.99 mg/kg. The contents of the samples taken from 0-20 cm depth of soil were 0.34 mg/kg and the soil samples of 20-40 cm depth were 0.33 mg/kg and 0.34 mg/kg. Wolf (1971) in terms of boron boundary values in the soil compared to the province of Şanlıurfa Siverek district in terms of boron content of wide soil groups at a depth of 0-20 cm 65.78% very little (<0.4 mg / kg), 26.32% less (0.5- 0.9 mg / kg, 7.90% was sufficient (1.0-2.4), at 20-40 cm depth, 81.58% was found to be very small, 15.79% was low and 2.63% was sufficient (Table 2). The aim of the study was to determine the general nutritional status of some olive orchards in the center and districts of Şanlıurfa in the same region Söylemez et al. (2017) reported similar results.

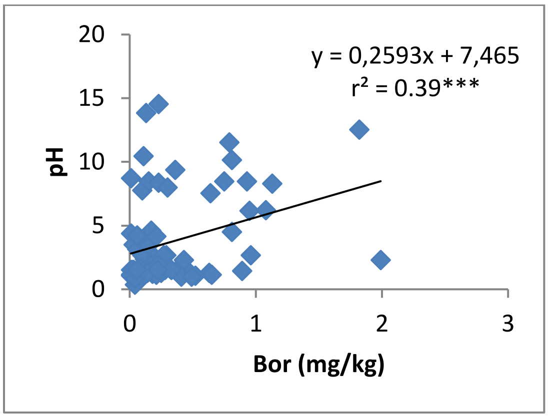
Relationship Between Boron Content and Some Other Soil Properties

The relationship between some physical and chemical properties of soil properties and boron contents can be found in Table 3. As can be seen from the analysis of the table, the pH content (r: 0.39 ***; Fig. 2) and the lime content (r: 0.32 ***; Fig. 3) have positive correlations with boron. In addition, the negative content (r: -0.56 ***) relationship between the pH content of the soil and the clay content, whereas a highly positive ones were determined between the content of the silt (r: 0.37 ***) and lime (r: 0.43***). It has been identified that there is the negative (r: - 0.66 ***) relationships between the salt content of the soils and the sand contents, while the salt content of the soils and the silt (r: 0.59 ***) and the organic matter (r: 0.37 ***) were significantly positive. Parlak et al. (2008) in the study which aims to determine the productivity status of the agricultural lands of the Eceabat district of Çanakkale, found similar results between the salt content of the soils and the sand, silt and organic matter content characteristics. In a study conducted in a different region, chemical fractions of the region of Tokat Kazovası and another study in which the relationships between these fractions and soil properties were determined, similar results were reported between the salt, sand and salt and silt and organic matter properties of the soils (Saltalı and Akın 2010). Negative significant (r: -0.40 ***) relationship was determined between clay content and silt content of soils. Soba et al. (2015) Ankara University Faculty of Agriculture Haymana research and application farm in the study of the productivity status of the soil clay and silt content of the soil properties have obtained similar results. The sand content of silt (r: -0.85 ***) and organic matter (r: -0.29 *) were determined as negative significant relationships between them. Significant relationships were determined between the lime content of the soils (r: 0.52 ***) and the organic matter (r: 0.32 ***).

Table 3. Correlation coefficients of the wide soil groups of Siverek district of Şanlıurfa province between boron and some soil properties.

	B mg/kg	pH	Salt (%)	Clay (%)	Sand (%)	Silt (%)	Lime (%)
pH	0.39***						
Salt (%)	-0.09	0.08					
Clay(%)	-0.07	-0.56***	0.04				
Sand (%)	-0.01	-0.07	-0.66***	-0.15			
Silt (%)	0.04	0.37***	0.59***	-0.40***	-0.85***		
Lime (%)	0.32***	0.43***	-0.14	-0.14	0.04	0.04	
OM (%)	0.01	0.01	0.37***	0.10	-0.29*	0.22	0.32***

* significant at 0.05 level, *** significant at 0.001 level



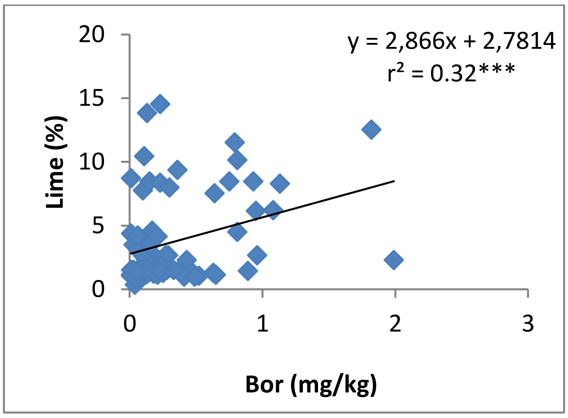


Figure 2. The relationship between the soil content of available boron and pH content

Figure 3. The relationship between the soil content of available boron and Lime content

CONCLUSION

It was tried to determine the wide soil groups in the Siverek district of Şanlıurfa province, the available boron state and its relationship with some soil properties. As a result, the soil of the wide soil groups in the province of Siverek in terms of soil reaction in general is suitable for planting with a slightly alkaline; as having a salt-free class they show a lack of any problems when considered in terms of salinity. It is determined that the soil of the wide soil groups of Siverek district of Şanlıurfa province has 8 different texture classes and 72.41% of the total amount of clayey soils, silty clayey clay and clay containing soils are found in the lands. It has been determined that the investigated soil has calcareous and medium calcareous environments in terms of lime and it has been observed that it has low and medium amount of organic content in terms of organic matter. In terms of the available boron of the studied Siverek district, it was determined that the amount of available boron contents of the soil (0-20 and 20-40 cm) at both depths (0-20 and 20-40 cm) was insufficient with very low and low. Boron fertilization should be done in order to increase the yield in this land.

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Effects of soil and environmental factors on the site productivity of pure Oriental beech forests in Akkuş region of Turkey

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Abstract

Oriental Beech grows naturally in the Eastern Caucasus, Northern Iran and, Crimea, from the west of the Balkans towards Anatolia. Akkuş Region of Turkey is one of the moist ecosystems where this tree species spread optimally. In this spread area, the change in local site factors affects site productivity. In this study, the correlations between the height growth of pure Oriental beech forests between 1200-1500 m altitudes in Akkuş region and some soil characteristics and location factors were investigated. 40 sample plots were taken from normally covered Oriental beech stands. In the sample plots, soil profiles were dug and soil sampling was performed according to genetic soil horizons. The location factors of the sample plots in the field were determined, and $d_{0.30}$ diameter, $d_{0.30}$ age, and upper height were measured in 4-6 trees with upper stand height. The site productivity (site index) was determined based on the correlation between standard age and upper stand height. Physical and chemical soil analyses were performed in the soil samples taken.

The correlations between the productivity indexes (site index) of the sample plots and the local ecological characteristics of the site were tested by correlation analysis. Positive correlations were determined between site index and the land slope degree and altitude (respectively $p<0.05$, $r=0.438$; $p<0.05$, $r=0.211$) . There are negative correlations between soil properties of the average amount of clay ($p<0.01$, $R=-0.206$) the average amount of silt($p<0.01$, $R=-0.247$), field capacity ($p<0.01$, $R=-0.500$), fine soil weight ($p<0.05$, $r=-0.179$), soil reaction ($p<0.01$, $r=-0.575$), and site index, while there are positive correlations between horizon A_h's organic matter ($p<0.05$, $r=0.340$), the average amount of sand ($p<0.01$, $r=0.258$), physiological soil depth ($p<0.01$, $r=0.212$), skeleton weight ($p<0.01$, $r=0.197$), and site index.

Keywords: Site index, moist ecosystem, slope, altitude, soil physical properties, Akkuş

INTRODUCTION

The growth of forest stands depends on their location in the stand and numerous factors including basic resources such as light, water, and nutrients the actual physical sizes of which can be reached. All these factors interact and change in space and time to be expressed together with the observed growth rate (Cienciala et al. 2016). This interaction and change take place in the form of a series of dynamic events different from its surroundings (matter and energy circulation and transformations) within the boundaries of an ecological unit called site. The effects of the factors that constitute the site on the formation of the characteristics of the site and site productivity are not similar.

The silvicultural practices to be performed in forest ecosystems and the management plans require safe site productivity. The estimation of growth and product in forest ecosystems can be achieved by the accurate assessment of productivity. Despite the suitability of site productivity estimations developed for tree species in forest management (Fernández et al. 2004), the change of local ecological conditions species (edaphic, topographic, climatic) for the same tree may show a correlation contrary to estimations. Although the change of site productivity is determined depending on certain environmental conditions, it can also be evaluated within the conceptual framework of site quality as the characteristic vegetation production capacity of the field (Hägglund, 1981). Most of the site quality studies were carried out in even-aged stands (planted or naturally regenerated) (Herrera and Alvarado, 1998).

There are various methods to estimate the site quality/productivity, including those based on the measurement of the forest (Daubenmire, 1976; Clutter *et al*., 1983 ; Shafer, 1989; Schönau and Aldworth, 1991; Vanclay, 1994). However, the most frequently used method in even-aged stands is the estimation of the site index as a measure of productivity. The most commonly used and mostly accepted method to evaluate the actual site productivity and the growth reaction of trees in forestry is the measure of upper stand height reached at a certain age, which is known as site index (SI). The forest trees and undergrowth in forest ecosystems tend to be shaped according to (climate and soil conditions etc.) (Cajander 1949; Childs and Flint 1990; Sims et al. 1996; Wang and Klinka 1996; Salemaa et al. 2008). Therefore, the nutrition, thermal and hydrological regimes of the soil significantly affect the site productivity. The hydrological conditions of sites depend not only on the physical characteristics of the soil but also on the topographic position and ambient weather conditions (Childs and Flint 1990; Nyberg 1996; Mäkitalo 2009; Campbell et al. 2013). For forestry management, the effect of location factors (slope, aspect, altitude, topographic position) on the characteristics and productivity of forest areas cannot be ignored.

Site productivity is largely determined by the physical and chemical properties of the soil, however, it is also affected by climate factors such as precipitation, temperature and the length of the growing season. Both physical and chemical soil properties are used in soil-site methods to estimate the site productivity (Fontes et al. 2003, Stape et al. 2004, Sampson et al. 2008, Almeida et al. 2010,Vega-Nieva et al. 2013). When the physical, chemical and biological properties of the soil are used, site productivity/site quality is generally better estimated (Subedi and Fox, 2016).

Numerous soil-site studies attempted to associate the measured soil properties with the site index (SI) (Carmean 1975, Hagglund 1981, Bravo and Montero 2001, Fontes et al. 2003) Nevertheless, it is quite difficult to measure the site productivity/site quality from soil properties in forest ecosystems due to the complex correlations between stand productivity and soil properties. The site quality and stand productivity can be approached from a different perspective, and site factors can be considered as a function of geoclimatic variables (Pokharel and Froese 2009; Bontemps and Bouriaud 2014).

In soil-site studies, regression techniques were frequently used to estimate site productivity from the topographical and edaphic characteristics of a site (Carmean 1975, Baker and Broadfoot 1979, Wang 1995, Beaulieu et al. 2011). To estimate the SI by developing a regression equation only with soil properties is also another method. Along with the genetic characteristics and climate characteristics, soil as the source of both water and nutrients is the most important factor affecting the growth of trees. Both physical and chemical soil properties may affect tree height depending on the site conditions.

There are many studies investigating the correlations between the height growth of trees and site factors, in other words, the correlations between SI and site factors. In these studies, the correlations between the site factors of both naturally grown species (Klinka and Carter 1990; Kayhara et al. 1997; Günlü et al. 2006; Johansson 2006; Özkan and Kuzugüdenli 2010; Karataş et al. 2013;) and the species brought to the area by planting (Curt et al. 2001; Sanchez –Rodriguez et al. 2002; Louw and Scholes 2005; Tüfekçioğlu et al. 2005; Yilmaz et al. 2008; Güner et al. 2011; Karataş and Özkan 2017) and site productivity was investigated. In this study, in the natural sites of oriental beech, which is one of the important tree species of Turkey, in Akkuş region of the Eastern Black Sea Region, the correlations between SI and site factors were investigated at altitude levels (1200 -1500 m) where unique ecological conditions are dominant. Oriental beech ranks number two in terms of spread area and ranks number one in terms of the amount of growing stock among leafy species (1.96 million hectares). Approximately 41% of leafy normal high forests in Turkey consist of Oriental beech forests (Anonymous, 2015).

MATERIAL AND METHOD

The research area is geographically located in the Eastern Black Sea Section of the Black Sea Region. The sample plots were selected from Ordu-Akkuş region, from the west of the Eastern Black Sea section where pure Oriental beech (forests are spread. Akkuş region, which is one of the places where the beech is optimally spread, is located within the fields that are under the influence of the sea and within Canik-Giresun Mountains Site region (Kantarcı, 2005a) (Figure 1). Within the scope of the study, 40 sample plots were taken from Akkuş region (20 sample plots were used from Yılmaz 2005).

Figure 1. Location of the research area.

In Akkuş region surrounded by beech forests on all sides, the average annual amount of precipitation is 1092,9 mm and the average annual temperature is 7.9 ^{o}C. The average temperature in four summer months is 15.4 ^{o}C (Yılmaz 2005). Since the mountain ranges in the region are parallel to the coastline, moist air masses bring plenty of precipitation in the region. The heights of the mountains and their positions against the prevailing north-west winds are more or less effective on the precipitation regime of the region. Furthermore, the river valleys crossing the mountain chains, which are parallel to the coastline, (Akçay, Cevizdere) ensure that the maritime climate is effective up to the interior parts. The climate analysis of Akkuş region was performed according to the Thornthwaite (1952) method, and it was determined as the "humid, high temperature (mesothermal) climate close to the oceanic climate with little or no water deficient" represented by the “B4 B'1 r b'4” symbol (Table 1).

There are totally 22649 hectares of pure Oriental beech forests in Akkuş region. 7350 hectares of this forest area is between 1200-1400 m altitudes while 8300 hectares of which is between 1000-1200 m altitudes. After 1400 m, the area of beech forests decreases up to 2278 hectares (Anonymous, 2015). The average altitude and average slopes of the sample plots are 1330 m and 36%, respectively, and they were taken from the soils developed from andesite-basalt bedrock. The dominant aspect of the sample plots is in the north aspect direction.

The sample plots were taken from the boundaries of Akkuş Forestry Department Akkuş Forest Sub-district Directorate. The average altitude of Akkuş region from sea level is 1313 meters and the horizontal distance from the sea is 75 km. The district is almost surrounded by beech forests on all sides. There are significant amounts of beech forest areas within the boundaries of Göllüce, Salman and Düzdağ forest sub-district directorate.

Table 1. Climate analysis of the research area.

Climate variables	Months												Vegetation period		
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Inside	Outside	Annual
TEMP (ºC)	-2,6	-1,6	2,6	7,6	10,2	14,5	16,2	15,2	13,3	11,3	7,4	1,1	13,5		7,9
PREP (mm)	74,9	89,1	60,6	136,2	180,8	69,0	51,1	31,6	85,0	84,9	96,4	133,3	502,4	590,5	1092,9
AE (mm)	-	-	13,7	43,0	64,6	92,7	104,8	84,2	70,4	55,2	31,4	4,6	471,8	92,7	564,5
WD (mm)	-	-	-	-	-	-	-	-	-	-	-	-	0,0	0,0	0,0
WS(mm)	74,9	89,1	46,9	93,2	116,2	-	-	-	-	-	-	108,1	116,2	412,1	528,4
ARH (%)	79,2	79	76,1	78,8	78,8	76,8	81,4	81,2	80,4	74,8	72,8	79,6	78,9	77,6	78,2
ACD	11,5	12,5	12,5	16,0	19,5	15,5	18,0	20,5	12,5	8,5	16,5	15,0	92,5	86,0	178,5
AOD*	14,0	13,0	13,5	10,5	9,0	8,5	9,5	8,0	11,5	11,5	8,5	14,0	58,0	73,5	131,5
PD	10,5	9,5	10,0	15,0	15,0	8,0	8,0	5,0	9,5	11,0	8,0	11,0	56,5	64,0	120,5
FD	0,5	1,5	3,0	1,0	0,0	2,0	1,0	0,0	0,5	1,0	0,5	0,5	4,5	7,0	11,5

TEMP: Temperature, PREP: Precipitation, AE: Actual evapotranspiration, WD: Water deficiency, WS: Water surplus ARH: Average relative humidity, ACD: Average cloudy days, AOD: Average overcast days, PD: Precipitation days, FD: Foggy days, * : Fully covered sky

The sample plots were taken by selected sampling, and their sizes vary between 400 and 600 m^2 according to the crown cover. After the boundaries of the sample plots were determined, the trees included in the sample area were numbered in a clockwise direction, and the root collar diameter and chest height diameter of all of them were measured. The height measurement was performed in all trees the diameter measurement of which was performed, and the age of the trees was determined by counting the increment from 0.30 cm height. Carus's (1998) site index yield table for even-aged beech forests was used for the productivity indexes of sample plots.

Method

Soil Properties

In the sample plots, soil profiles were dug and absolute and physiological soil depths were determined (Kantarcı, 2000). In the soil profile, mineral soil horizons were separated and introduced according to genetic soil horizons, and the soil samples were taken in two ways: bag sampling and volume sampling. The fine soil weight (gr/lt) and the skeleton weight (gr/lt) of soil samples were determined using the volume samples taken according to Kantarcı 2005b. 176 soil samples taken from sample plots were ground and sieved following air dried and weighed before and after the skeleton has been removed.

The particle size analysis of soil samples was performed according to the Bouyoucos hydrometer method, and the soil types were determined according to international texture classes (Gülçur, 1974; Karaöz, 1989a).

Soil reaction (pH): was measured by pH meter with a glass electrode. The soils were mixed with distilled water by 1:2,5 for actual acidity, and they were mixed with 1N KCl by 1:2,5 for potential acidity, they were kept overnight and then measured (Gülçur, 1974; Karaöz, 1989b; Kantarcı, 2005b). Organic carbon in the soil was determined by Walkley-Black wet burning method. The organic matter of the soil was calculated based on organic carbon (Gülçur, 1974; Kantarcı, 2005b). The available water capacity

(AWC) of soil samples were calculated based on the differences of field capacity moisture and wilting point moisture values determined in soil moisture device with pressure table (Karaöz 1989a; Kantarcı, 2005b).
Location Factors

The altitudes of the sample plots selected within the scope of the research vary between 1230 m and 1485 m and their slopes vary between 5% and 70%, and the research area was divided into two altitudinal zones and four slope groups.

Slope (%)	Slope Class	Slope group	Altitude (m)	Altitudinal zones
(0 - 16)	Low and moderately sloping	I	1200 – 1350	I
(17 - 35)	Moderately high sloping	II	1351 – 1500	II
(35 - 58)	Strongly sloping	III		
(>58)	Steep	IV		

Statistical analysis
The simple correlation analysis was performed between the SI values of sample plots determined and the physiographical factors and soil properties of the site. SPSS package program was used for this process (SPSS 2015).

RESULTS AND DISCUSSION

60% (24) of the sample plots are located in the 1st altitudinal zone while 40% (16) of them are located in the 2nd altitudinal zone.
The site indexes of the sample plots are significantly positively correlated with altitude despite a low correlation coefficient. In other words, an increase is observed in site indexes along with an increase in altitude in Akkuş region ($p<0.01$, $r=0.211$) (Table 2). In the literature, it is generally thought that there is a decrease in site indexes along with an increase in altitude (Klinka et al. 1996; Klinka and Chen 2003; Yılmaz 2005; Ercanlı et al. 2008; Socha 2008; Özkan and Kuzugüdenli 2010; Öztürk 2012; Yilmaz et al. 2015). Although there is no correlation between the height growth of forest stands and altitude in some studies (Kalay 1996; Yılmaz 2005), there are also positive correlations between altitude and height growth (Özkan et al. 2005; Güner 2008). These differences between altitude and SI values can be explained depending on the altitude variation of the study area and the change of other site factors, as well as the ecological characteristics of tree species. In general, the climatic characteristics changing with increasing altitude also negatively affect the site conditions, and the productivity of forest trees decreases along with the shortening of the growing period. In a part of the study carried out by Yılmaz (2005), no correlation was found between altitude and the SI of Oriental beech in Akkuş region. Within the scope of the study, 30 sample plots were taken between 1230-1550 meters. This study was carried out by taking 40 sample plots from Oriental beech stands between 1200-1500 meters altitudes. These altitudes are the 2nd altitudinal zone where Oriental beech spreads optimally. The 1st altitudinal zone, where Oriental beech spreads optimally within the boundaries of Akkuş Forestry department, is between 1000-1200 meters (a forest area of 8300 hectares). The positive correlation between altitude factor and the SI of Oriental beech stands is specific to the studied altitude climate zone of Akkuş region. The absence of temperature reduction that would shorten the growing period depending on the increasing altitude between 1230 meters and 1485 meters where sample plots were taken, and also the availability of sufficient moisture did not negatively affect the organic and inorganic decomposition. Along with the increase in altitude, the thickness of B horizon (TBH), thickness of A horizon (TAH), physiological soil

depth (PSD) and excavation depth (ED) in soil profiles, and the increase in average amounts of silt and clay and the reduction in average amount of sand of soil samples confirm conclusion (Table 2, Table 3). Along with the increase in altitude, TBH ($p<0.01$, r=203), TAH ($p<0.05$, r=0.157), PSD ($p<0.01$, r=0.480) and ED ($p<0.01$, r=0.339) increased, and increased PSD and ED increased the SI values ($p<0.01$, r=0.212; $p<0.01$, r=0.268).

One of the most important site factors affecting the productivity of forest trees is the degree of slope. The SI values of forest trees decrease with an increase in the degree of slope (Sharma et al. 2012; Yılmaz 2005; Kalay 1996; Ercanlı et al. 2008; Yilmaz et al. 2015). In this study, the SI values of Oriental beech increased along with an increase in the degree of slope. There is a positive correlation between the degree of slope and SI values ($p<0.01$, r=0.438). This correlation coefficient was found to be r=0.262 in the study carried out by Yılmaz (2005) in the region. However, the author stated that it was not very true to generalize this argument on the grounds that the sample plots in the good productivity class are represented in a small number. The positive correlation between SI and slope resulting from unique ecological conditions of Akkuş region was clarified by increasing the number of sample plots in less sloping areas. The fact that the generally known positive effect of low and moderately sloping bottom lands on productivity was found to be opposite in Akkuş region may be due to the weak and moderate drainage feature of the sample plots taken from low and moderately sloping lands. Since the mountain ranges in the region where the study was carried out are parallel to the coastline, moist air masses bring plenty of precipitation in the research area and its surroundings. Indeed, Akkuş region was characterized by "very humid, low-temperature climate type without water deficiency" (Yılmaz 2005).

There is excess water in the soil during the vegetation period. Furthermore, during the vegetation period, moist and saturated air masses move towards low and moderately sloping fields over high sloping fields and accumulate over beech forests in these areas (Figure 2).

The fact that the soil is saturated with water due to precipitation, low degree of slope and soil characteristics (particle size, skeleton, fine soil weight) and also the fact that transpiration does not occur in the stand the top roof of which is covered with moist air masses adversely affect the nutrition and growth relationships in trees. In these sites, suberization and mossiness occur in trees due to excess moisture (Figure 3) In the fields with high slope and sufficient soil depth, uptake of water and nutrients from the soil is not interrupted since there is less water in the soil and photosynthesis organs are further exposed to the sun. Because Oriental beech prefers high sloping lands with well-drained, deep, permeable soils (Saatçioğlu 1979). There are significant correlations between SI values of Oriental beech and the soil properties of the site. There was a positive ($p<0.01$, r=0.258) correlation between the particle diameter of soils and the average amount of sand and a negative ($p<0.01$, r=-0.206 and $p<0.01$, r=-0.247) correlation between average amounts of silt and clay, respectively. The increased amount of clay and silt and decreased amount of sand in soils lead to the development of finer textured soils. In the sites located in the region where there is adequate precipitation and the slope is low, the increase in silt and clay amounts of soils further worsen the poor drainage conditions. The SI values of the low sloping sample plots, where drainage is blocked and the formation of standing water was observed locally, were low. The fact that the most important factors affecting the productivity of Oriental beech forests in the region are moisture in the atmosphere during the vegetation period, water held in the soil, the blocked drainage and the degree of slope of the land is also supported by the results of other correlation analyses. When the results of the correlation analysis presented in Table 2 are examined, it is seen that there are negative correlations between SI values and moisture content ($p<0.01$, r=-0.500) and fine soil weight (%) of the soils ($p<0.05$, r=-0.180) in the field capacity, and there are positive correlations between skeletal part of the soils (%) ($p<0.05$, r=0.197).

Table 2. Correlations between the SI and site factors

	ALT (m)	Slope (%)	Sand (%)	Silt (%)	Clay (%)	SW (%)	FSW (%)	FC (%)	ED (cm)	PSD (cm)	TAH (cm)	TBH (cm)	pH (KCl)	pH (Water)	AHOM (%)
SI (m)	,211**	,438**	,258**	-,247**	-,206**	,197**	-,179*	-,500**	,268**	,212**	-,212**	-,055	-,575**	-,331**	,340**
ALT (m)		,058	-,377**	,357**	,293**	-,031	,112	-,139	,339**	,480**	,157*	,203**	-,198**	-,289**	-,141
Slope (%)			-,286**	,139	,337**	,212**	-,206**	-,024	,085	-,015	-,321**	-,053	-,406**	-,355**	,099
Sand (%)				-,806**	-,905**	,193*	-,268**	-,416**	-,102	-,101	-,082	-,042	,101	,267**	-,046
Silt (%)					,488**	-,246**	,296**	,372**	,091	,063	,097	,038	-,096	-,378**	-,066
Clay (%)						-,122	,200**	,364**	,056	,090	,025	,041	-,083	-,123	,105
SW (%)							-,952**	-,370**	,042	,015	-,225**	-,048	-,045	,064	,002
FSW (%)								,367**	,008	,085	,167*	,186*	,029	-,072	,005
FC (%)									-,211**	-,262**	,120	-,069	,291**	,134	-,039
ED (cm)										,612**	,372**	,349**	-,139	-,158*	,211**
AWC (cm)											,408**	,597**	-,051	-,019	,298**
TAH (cm)												,184*	,285**	,273**	,200**
TBH (cm)													-,074	,034	,014
pH (KCl)														,825**	-,063
pH(Water)															,040

*: Significance at 0.05 probability level **: Significance at 0.01 probability level. SI: Site index, ALT: Altitude, SW: Skeleton weight, FSW: Fine soil weight, FC:Field capacity, ED: Excavation depth, PSD: Physiological soil depth, TAH: Thickness of A horizon, TBH: Thickness of B horizon, AHOM: Amount of organic matter of A horizon,

Table 3. Variation of the average SI and soil properties of the sample plots according to altitudinal zones.

	Altitudinal zones	NSP	Mean ± Std. Dev.	Min.	Max.		Mean ± Std. Dev.	Min.	Max.
SI (m)	I	24	25,94 ± 2,34	20,40	29,30	ED (cm)	115,82 ± 20,43	60,00	140,00
	II	16	25,53 ± 2,43	23,10	30,20		119,39 ± 8,2	90,00	130,00
Sand (%)	I	24	62,37 ± 16,36	36,00	91,00	PSD (cm)	91,75 ± 25,11	30,00	120,00
	II	16	48,45 ± 13,76	26,00	86,00		95,00 ± 17,93	60,00	115,00
Silt (%)	I	24	17,09 ± 7,36	5,00	35,00	ASD (cm)	73,76 ± 17,99	15,00	97,00
	II	16	23,27 ± 7,9	5,00	37,00		72,15 ± 17,96	23,00	92,00
Clay (%)	I	24	20,85 ± 10,74	1,00	42,00	TAH (cm)	18,07 ± 4,38	11,00	28,00
	II	16	28,36 ± 10,49	9,00	49,00		18,73 ± 2,85	15,00	23,00
FSW (%)	I	24	84,06 ± 13,11	33,54	99,00	TBH (cm)	29,44 ± 11,94	,00	52,00
	II	16	85,73 ± 13,26	50,91	98,95		33,21 ± 13,02	,00	50,00
SW (%)	I	24	15,94 ± 13,11	1,00	66,46	pH (KCl)	4,50 ± 0,48	3,60	5,40
	II	16	14,27 ± 13,26	1,05	49,09		4,43 ± 0,33	3,80	5,20
FC (%)	I	24	32,24 ± 6,62	14,17	43,20	pH(Water)	5,36 ± 0,57	4,10	6,40
	II	16	32,90 ± 4,71	21,80	42,24		5,14 ± 0,43	4,40	5,90
WP (%)	I	24	21,25 ± 5,3	9,33	31,67	AHOM (%)	7,33 ± 2,99	3,78	14,17
	II	16	23,51 ± 4,38	14,62	30,92		5,61 ± 0,82	4,52	7,45
AWC (%)	I	24	10,99 ± 4,16	2,73	30,14	OM (%)	3,02 ± 2,98	,23	14,17
	II	16	9,39 ± 2,74	4,30	14,76		2,91 ± 1,88	,47	7,45

NSP: Number sample plot, SI: Site index, FSW: fine soil weight, S: Skeleton weight, FC:Field capacity, WP: Wilting point, AWC: available water capacity, ED: Excavation depth, PSD: Physiological soil depth, ASD: Absolute soil depth, TAH: Thickness of A horizon, TBH: Thickness of B horizon, AHOM: Amount of organic matter of A horizon, OM: Organic matter

The moisture content in the field capacity of the soils corresponds to the equivalent moisture retained in capillary pores after leachate leach out of the soil. In fact, it is the moisture equivalent to the upper limit of water retained by capillarity in the soil. While it is considered by some scientists as a value close to the maximum capacity of capillary water and normal capillarity moisture terms (Irmak, 1972), it is considered by some scientists as the maximum moisture content that can be retained in the root zone soil of free-draining soils (Özhan, 2004). The negative correlation between the SI values and the moisture contents in field capacity means a reduction in the productivity of Oriental beech depending on the increase in the amount of water retained in the capillary pores of soils. Oriental beech, which prefers deep and well aired and drained soils, is not well developed in these sites. The fact that capillary pores are saturated with water for a long period of time also negatively affects the aeration in time.

Figure 2. Top roof covering of the stand by moist air masses in the research area.

Figure 3. Mossiness in trees in Oriental beech stands on flat grounds.

The positive correlation between the SI of Oriental beech and the amount of skeleton of soils can be partially explained by the fact that the soil skeleton positively affects the productivity by allowing aeration. Because the percolation of the water is accelerated, drainage becomes easier and aeration increases in the sites where the skeleton part of the soil is more. However, it is usual to expect a negative correlation between the amount of skeleton and the site indexes in the sites where the average skeleton reaches 60-70% (Yılmaz 2005)

Increased fine soil weight in soils slows down percolation, complicates drainage and reduces aeration. In the research area, while the lowest fine soil section varies between 50.91% and 68.47% in the low and moderately sloping sample plots, the lowest fine soil section varies between 33.54% and 45.92% in high and steep sloping fields. In this region, the reduction of the fine soil weight, and the increase in skeleton weight in terms of facilitating aeration and drainage in the soil increased the productivity of forest trees. However, this can be said for the low sloping sample plots of the research area where the soil depth is sufficient, dominated by the moderately fine textured soils with no lack of water and nutrients.

One of the physical soil properties affecting the productivity of forest trees is the soil depth. Soil depths are known as physiological depth, absolute depth, and excavation depth. In general, the productivity of forest trees increase with increasing soil depths (Çepel ve ark., 1977; Daşdemir 1987; Kalay 1989; Leblanc 1994; Yılmaz 2005; Karataş et al. 2013; Paulo et al. 2014; Güner et al. 2016).

Table 4. Variation of site indexes and soil properties according to slope groups

	SG	NSP	Mean ± Std. Dev	Min.	Max.		Mean ± Std. Dev	Min.	Max.
SI (m)	I	8	25,28 ± 1,32	23,60	27,30	ED (cm)	122,38 ± 4,31	120,00	130,00
	II	12	23,81 ± 2,17	20,40	26,60		112,61 ± 18,67	60,00	130,00
	III	10	27,04 ± 1,45	24,70	28,90		110,95 ± 25,55	60,00	140,00
	IV	10	27,07 ± 2,52	23,10	30,20		122,61 ± 6,81	120,00	140,00
Sand (%)	I	8	69,52 ± 15,58	41,00	91,00	PSD (cm)	93,48 ± 20,44	65,00	120,00
	II	12	48,82 ± 13,31	32,00	86,00		93,04 ± 25,15	30,00	120,00
	III	10	53,19 ± 14,31	36,00	75,00		95,57 ± 18,92	60,00	110,00
	IV	10	57,22 ± 16,86	26,00	87,00		90,04 ± 25,42	50,00	115,00
Silt (%)	I	8	15,90 ± 7,50	5,00	32,00	ASD (cm)	78,14 ± 5,62	70,00	84,00
	II	12	22,41 ± 7,37	5,00	36,00		69,43 ± 26,76	15,00	92,00
	III	10	20,38 ± 7,99	6,00	37,00		68,19 ± 16,58	47,00	97,00
	IV	10	18,96 ± 8,43	5,00	35,00		76,87 ± 13,50	63,00	97,00
Clay (%)	I	8	14,57 ± 9,28	1,00	33,00	TAH (cm)	20,48 ± 4,45	17,00	28,00
	II	12	28,82 ± 11,06	9,00	47,00		18,83 ± 2,54	14,00	21,00
	III	10	26,95 ± 8,73	10,00	42,00		17,50 ± 3,56	12,00	22,00
	IV	10	24,17 ± 10,31	8,00	49,00		16,57 ± 3,73	11,00	23,00
FSW (%)	I	8	89,60 ± 6,54	68,47	96,93	TBH (cm)	35,57 ± 11,34	25,00	52,00
	II	12	86,44 ± 12,47	50,91	98,95		28,04 ± 15,91	,00	50,00
	III	10	83,56 ± 16,17	33,54	99,00		28,05 ± 8,04	19,00	40,00
	IV	10	79,56 ± 13,77	45,92	95,45		31,87 ± 11,55	16,00	50,00
AS (%)	I	8	10,40 ± 6,54	3,07	31,53	pH (KCl)	4,69 ± 0,34	4,10	5,20
	II	12	13,56 ± 12,47	1,05	49,09		4,66 ± 0,40	4,00	5,40
	III	10	16,44 ± 16,17	1,00	66,46		4,18 ± 0,26	3,80	4,80
	IV	10	20,44 ± 13,77	4,55	54,08		4,37 ± 0,47	3,60	5,20
FC (%)	I	8	32,19 ± 7,07	14,17	43,11	pH (Water)	5,58 ± 0,52	4,80	6,40
	II	12	34,31 ± 5,00	21,80	43,20		5,38 ± 0,46	4,40	5,90
	III	10	30,84 ± 4,85	17,14	37,49		4,99 ± 0,46	4,10	5,90
	IV	10	32,53 ± 6,32	17,45	42,24		5,17 ± 0,51	4,40	6,10
WP (%)	I	8	22,22 ± 5,08	11,44	31,67	AHOM (%)	6,73 ± 2,43	4,37	9,32
	II	12	24,13 ± 5,21	13,05	30,30		5,84 ± 0,79	5,09	8,56
	III	10	20,41 ± 2,82	12,36	24,67		7,92 ± 3,81	3,98	14,17
	IV	10	21,63 ± 5,95	9,33	30,92		6,31 ± 1,86	3,78	8,90
AWC (%)	I	8	9,97 ± 3,93	2,73	19,10	OM (%)	2,58 ± 2,53	,32	9,32
	II	12	10,18 ± 4,91	4,51	30,14		3,07 ± 2,20	,47	8,56
	III	10	10,43 ± 3,62	4,30	17,17		3,51 ± 3,27	,57	14,17
	IV	10	10,90 ± 2,20	6,49	15,26		2,77 ± 2,37	,23	8,90

SG: Slope groups, NSP: Number sample plot, SI: Site index, FSW: fine soil weight, AS: Amount skeleton, FC:Field capacity, WP: Wilting point, AWC: available water capacity, ED: Excavation depth, PSD: Physiological soil depth, ASD: Absolute soil depth, TAH: Thickness of A horizon, BHK: Thickness of B horizon, AHOM: Amount of organic matter of A horizon, OM: Organic matter

In this study, there were positive correlations between the site index values and soil depths ($p<0.01$, $r=0.212$ with physiological soil depth; $p<0.01$, $r=0.268$ with excavation depth) (Table 2). However, the low correlation coefficient is remarkable. The fact that soil depths show a lower correlation than the other soil properties is specific to this site. For the research area, the average absolute soil depth is 74 cm, the physiological soil depth is 91 cm and the excavation depth is 117 cm (Table 4). There is no restriction related to soil depth in terms of the nutrition of plants.

Another edaphic factor affecting the productivity of forest trees is the soil reaction. Soil reaction may have different degrees of effects on growth of trees depending on tree species, tree age, climatic conditions, and other ecological conditions. In addition to positive correlations between soil reaction and the SI values of trees (Brown 2007; Yilmaz et al. 2015), negative correlations (Yilmaz et al. 2008; Yilmaz et al. 2015) were also mentioned. In natural spread area, Oriental beech forests grow in soils with degrees between 4.1 - 6.0 pH (NKCl) (Çepel 1995) and 3.5 – 6.6 pH (NKCl) (Yılmaz 2005), 4.88 – 5.35 pH (H_2O) (Sariyildiz et al. 2005; Sariyildiz and Küçük 2009). In this study, there was a significant negative correlation between soil reaction (pH) (NKCl) and the SI values of Oriental beech ($p<0.01$, $r=-0.575$), the average soil reaction was 4.47 pH (NKCl), and average limit values varied between 3.60 –

5.40 pH (NKCl). The increase in pH between these limit values decreases the SI values. In the research area, the sample plots where the SI values are low are the low sloping sample plots. It is interesting that the average pH values of low sloping sample plots are higher (Table 4). It is known that Al^{+3} and H^{+} ions in the soil cause low soil pH and that other cation (such as Ca^{+2}, Mg^{+2}) cause high pH. In the research area, the changeable Ca^{+2} and Mg^{+2} amounts of the sample plots with high pH values are lower than those of the sample plots with low pH values and high SI values. The correlation between soil pH and SI may be due to the effect of nutrient uptake. Since transpiration from plant leaves will decrease in the sites with high air humidity like the research area, the groundwater will not be absorbed by plant roots and especially the leaves will not get the cations such as Ca^{+2}. It is reported that fungi develop in leaves that cannot get enough Ca^{+2} (Kantarcı 2000). Since the development of leaves is adversely affected and the leaf surface area will decrease in sample plots with high Ca^{+2} and high pH, photosynthesis will be adversely affected and the SI values will decrease.

CONCLUSION

Site productivity is determined by the local ecological conditions (climatic, edaphic and topographic) of the site, along with the genetic characteristics of species. While site productivity is generally expected to decrease with an increase in some spatial factors such as land slope and altitude, productivity may increase when evaluated together with other local ecological conditions (climatic and hydrological). In this study, a similar correlation was revealed under local site conditions in Akkuş region of Eastern Black Sea Region of Turkey. It is quite interesting that SI decreases along with a decrease in altitude and the degree of slope of the field in Akkuş region, which is one of the optimum sites of Oriental beech in Turkey. It is very important to know the correlations between such sites and productivity for forestry practices to be performed and planned management organizations. The time and forms of the interventions to be performed to forest ecosystem at a limited elevation belt (1200-1500 m) and under certain topographical and edaphic conditions (flat and low slope, fine-textured soils) and the interventions to be performed in the sites with regional ecological conditions (high slope, hillsides and areas with high altitudes) may be different. Because the SI and the amount of above-ground biomass of the same tree species will be different in the two different sites described. Therefore, the time of intervention to the forest ecosystem will change. Furthermore, the areas of usage of forest products to be produced from these sites may also change. For instance, the properties of wood produced in humid sites and the properties of wood produced in very humid-wet sites will be different. To know the local ecological characteristics of the site well in the afforestation and natural regeneration studies in potential areas will provide a basis for the management of similar areas.

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The macro and micro nutrition status of Anatolian chestnut in Inegol (Bursa-Turkey)

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Abstract

Chestnut is a plant that is grown in limited areas in the world and is profitable for its producer. In spite of this, the determination of nutrient elements and fertilization studies in chestnut orchards are insufficient. This study was carried out to determine the mineral nutritional status of Anatolian chestnuts cultivated in Inegol (Bursa) by soil and leaf analysis. In this research, the soil samples were taken from 25 different chestnut orchards (5 locations) in Inegol district only in April 2012. The chestnut leaves were sampled both in August 2012 and 2013. During both years, chemical and organic fertilization have not been done in the chestnut orchards. In soil samples, texture, pH, total salt, lime ($CaCO_3$), organic matter, total nitrogen, available phosphorus, potassium, calcium, magnesium, iron, zinc, manganese, and copper; In the leaf samples, macro and micro plant nutrient elements were analyzed except boron. The results of the analysis of the leaves and soil samples were compared with the limit values and the nutrient status and nutritional problems of the studied orchards were determined.

According to the results, it was determined that the analyzed soils were the mostly coarse-textured, less salty, slightly acidic reaction and inadequate to organic matter and lime. In addition, N, Ca and Mg contents of the soil is very low, the P content is at the limit values and K, Fe, Zn, Mn, and Cu contents were found to be within the limit values. Also, leaf analysis results show that the plant's nutrients (N, P, K, Ca, Mg) are inadequate or below the limit values. However, the contents of micronutrients (Fe, Zn, Mn, Cu) remained within their limits.

As a result, chestnut trees must be fertilized with macro nutrients for efficient and profitable production.

Keywords: Chestnut (*Castanea sativa* Mill.), productivity, nutrition

INTRODUCTION

Turkey has one of the most important and largest productions of chestnut in the Europa. The naturally spreading chestnut species in Turkey is the European chestnut (*Castanea sativa* Mill.), and chestnut production utilizes native cultivars. It was known thirteen chestnut species in the world and these species have located in northern hemisphere. One of the chestnut species is a *Castanea sativa* Mill. (European chestnut) which is native to Asia Minor (Soylu and Erturk, 1999).

However, studies on production, marketing, and characteristics of chestnut growers are very limited in the literatüre (Serdar et al. 2018). Chestnut can be consume fresh by roasting and boiling in Turkey, is used in making cakes and is widely used in the candy industry (Uylaser et al. 2014). Chestnuts have played an important role in human nutrition since ancient times. The term “bread tree” has been used in some places for chestnuts (Bounous et al. 2000).

According to the FAO (2019), worldwide chestnut production is 2.236.223 tons. Chestnut is highly regarded and widely consumed throughout Europe, America, and Asia. In addition, chestnuts are one of the most popular nuts in the oriental world. Chestnuts are mainly cultivated in China (1.939.719 t), Turkey (62.904 t), Republic of Korea (52.764 t), Italy (52.356 t) and Greece (36.000 t)

Since nutrient management is a critical aspect of crop production, nutrient recommendations have been developed for several fruit and nut species. Sufficiency or survey ranges for individual nutrients are routinely used by soil and plant testing facilities as a basis for providing fertilizer recommendations. The sufficiency range, used for foliar testing, indicates the values at which the tissue is at the optimal nutritional status, as determined by field testing (Bryson et al. 2014).

However, there is limited scientific data on chestnut management, in particular in the field of mineral nutrition and crop fertilization (Portela et al. 2007). On the other hand, studies done with young potted plants have shown that the crop responds to the application of mineral nutrients (El Kohen et al. 1992; Laroche et al. 1997), and therefore it is expected that a positive response to fertilization may also occur in the field. Pérez-Cruzado et al. (2011), used wood-bark ash, a product rich in Ca, K, Mg, and to a lesser extent P, as a fertilizer in a young chestnut orchard. They recorded an increase in the diameter and height of the trees and also an improvement in the nutritional status of the plants in terms of K, Ca, and Mg.

Chestnuts can grow and bear profitable crops of nuts without ever being fertilized, but to get the very highest yields a program of regular fertilization will be necessary. The higher cost can be easily offset by the high value of the crop. If chemical fertilizers are used then regular soil tests should determine the quantity and type. Regardless of what kind of fertilizer is used, it should be applied in spring and never any later than early June. Fertilizer applied later will result in tender late-season growth which will be subject to winter damage (Wahl 2002).

The aim of this study is to determine the productivity status of the orchards of the Anatolian chestnut which is an important source of income for the farmer in Inegol district of Bursa province in the Southeast Marmara Region.

MATERIAL AND METHODS

Site Properties

The region is located in the Marmara and the Aegean climate transition zone. In the 2012 and 2013 chestnut vegetation period (from March to October), the total amount of rainfall was 333.8 years in the first year and 396.3 mm in the second year. The average temperature in the period of the research is consistent with the average temperature long term years, and the total rainfall is consistent with the total rainfall long term years. Climate data for the research areas and periods are shown in Figure 1.

The study was carried out in 25 orchards in 5 location where intensive chestnut cultivation was made in İnegol district. Soil samples were taken only in April 2012 and leaf samples in August 2012 and 2013. Some location information about the sampling locations are shown in Table 1.

Soil Analysis

The pH of the soil samples in a mixture of 1 / 2.5 of soil pure water with pH meter; CaCO3 with calcimetric method; salt, conductometric method in saturation sludge; organic matter, according to the Walkley and Black titrimetric method; changeable K, Ca, Mg, Na photometric according to 1 N ammonium acetate method; availeble P, colorimetric according to Olsen method with 1.5 M sodium bicarbonate; Fe, Mn, Zn, Cu were spectrophotometrically analyzed by DTPA (Kacar 1995). The classification and interpretation of soil analyzes were done according to Kellog (1952), Forth and Jacobs

(1964), Soil Staff (1954), Evliya (1960), Schlincting and Blume, (1966), Kovancı (1969), Pizer (1967), Loue (1968), Viets and Lindsay (1973).

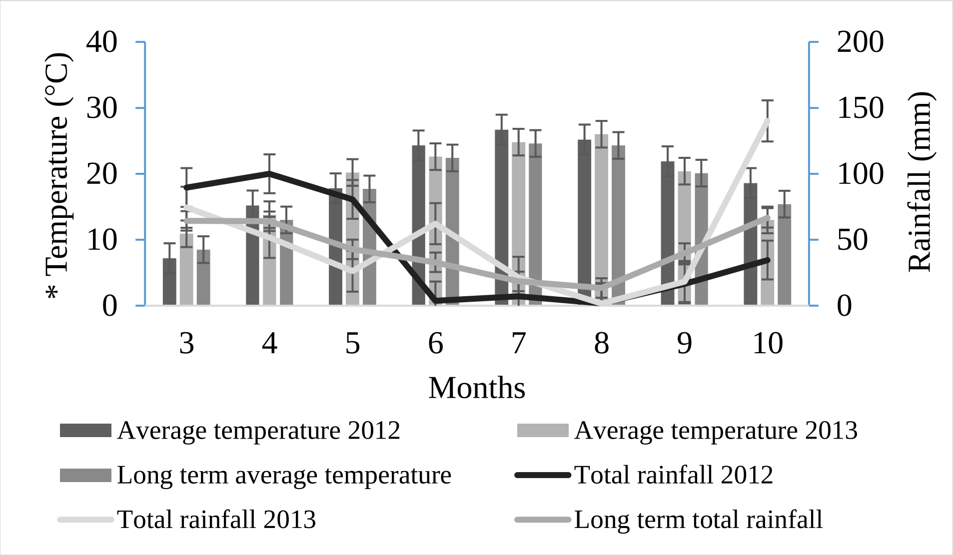

Figure 1. Climate data at the research area over two years (2012 and 2013). The values are shown (bars or symbols) means ± standard deviation (SD). The bars are shown the average temperature and the lines are shown total rainfall.

Leaf analysis

The samples were taken from the shoots on four sides of the tree and from the leaves in the middle size. Leaf samples taken from the chestnut orchards were brought to the laboratory in paper bags, washed with sterile distilled water and dried at 65 °C for 24 hours in the oven. The dried samples were grounded in the steel mill and had been made ready for the analysis (Kacar and İnal 2008). Total N analysis was performed according to Kjeldahl distillation method by using grounded leaf samples. Phosphorus, potassium, calcium, magnesium, iron, copper, zinc and manganese were determined from the samples obtained by wet burning method using ICP-OES (Inductively Coupled Plasma) device (Kacar and İnal 2008). Results were given as % dry matter for P, K, Ca, Mg and mg kg^{-1} in dry matter for Fe, Cu, Zn, Mn.

RESULTS AND DISCUSSIONS

Some physical and chemical status of orchard soils

According to the results of soil samples analysis, 48% of the soils were loamy, 24% were sandy loam and 28% were clay loam. All of the orchards in the A location have loamy soil structure. Other locations have sandy loam and clay loam soil structure characteristics (Table 2).

As it is known, chestnut is better grown in deep profile loamy soil structure (Soylu, 2004). According to the results of soil pH, all of the chestnut orchards are slightly acidic soils. Soil pH ranges between 5.57 and 6.86. The lowest pH values were recorded as average 6.09 and 6.10 at C and B locations, respectively. The chestnut tree is mostly grown in slightly acidic pH (Soylu 2004; Toprak and Seferoğlu 2013). The content of organic matter was determined below the value of the standard (2-3%) in all orchards. Organic matter content is important in terms of nutrient richness and organism activities of soils. The lowest organic matter content was found in location A (Average 1.47%), and the highest organic matter content was determined in location D (Average 1.79%). In the soil analyzes, the lime content of the soils is very low. Calcium is leached with precipitation in deep profile and loamy soils and its amount has decreased in the soil.

Table 1. Some location information about sampling locations.

Sampling no	Location No	Location name	Coordinates		Altitude (m)
			N	E	
1	A	Tahtaköprü	39.932463	29.633146	824
2			39.935017	29.635486	851
3			39.929757	29.640401	848
4			39.933225	29.634879	784
5			39.931875	29.640887	824
1	B	Bahçekaya	39.929199	29.630084	839
2			39.927594	29.628688	835
3			39.924987	29.627231	824
4			39.922474	29.625198	817
5			39.919262	29.624167	807
1	C	Mesruriye	39.919914	29.606384	849
2			39.918098	29.606354	836
3			39.916818	29.604594	827
4			39.914770	29.604169	862
5			39.916120	29.611118	843
1	D	Hilmiye	39.946680	29.589177	861
2			39.947552	29.587482	847
3			39.948967	29.585143	859
4			39.944259	29.589757	848
5			39.944509	29.585594	862
1	E	Saadet	39.925914	29.568821	876
2			39.924696	29.566584	863
3			39.922648	29.564271	817
4			39.921154	29.565609	849
5			39.920683	29.565393	867

However, the $CaCO_3$ content of the soil ranges between 0.22 and 0.55%. The highest $CaCO_3$ content was found at location D (Average 0.41%), while the lowest $CaCO_3$ content was recorded at location B (Average 0.34%). These values show that the soil is in the less calcareous soil class (0-1%). Soils are classified as low salty (<0.15%) according to salinity class. The highest salt content was found at location E (Average 0.100%) and the lowest salt content at location A (Average 0.078%).

The macronutrient status of soils

Macronutrient contents of chestnut orchards soils of the sampling locations are shown in Table 3. The total N% content of the sampled orchards soils were determined below the limit values (<0.090%).

Table 2. Some chemical and physical properties of soil in sampling orchards.

Locations	Texture Class	pH (1:2.5)	Organic matter (%)	Lime ($CaCO_3$ %)	Salt (%)
A 1	Loamy	6.36	1.32	0.38	0.083
A 2	Loamy	6.23	1.25	0.41	0.094
A 3	Loamy	6.20	1.41	0.24	0.084
A 4	Loamy	6.39	1.74	0.32	0.067
A 5	Loamy	6.58	1.34	0.43	0.061
Average		6.35	1.41	0.36	0.078
B 1	Sandy Loam	5.99	1.94	0.28	0.093
B 2	Loamy	6.26	1.32	0.35	0.101
B 3	Loamy	6.46	1.64	0.41	0.094
B 4	Sandy Loam	5.99	1.55	0.35	0.097
B 5	Sandy Loam	5.80	1.87	0.29	0.095
Average		6.10	1.66	0.34	0.096
C 1	Sandy Loam	5.68	1.52	0.22	0.083
C 2	Loamy	6.24	1.64	0.34	0.091
C 3	Loamy	6.28	1.88	0.43	0.068
C 4	Clay Loam	6.58	1.54	0.55	0.076
C 5	Sandy Loam	5.89	1.64	0.23	0.095
Average		6.09	1.64	0.35	0.083
D 1	Clay Loam	6.28	2.11	0.51	0.087
D 2	Clay Loam	6.57	2.04	0.47	0.076
D 3	Clay Loam	6.87	1.78	0.44	0.092
D 4	Loamy	6.24	1.64	0.34	0.082
D 5	Sandy Loam	5.57	1.36	0.28	0.090
Average		6.31	1.79	0.41	0.085
E 1	Clay Loam	6.27	1.22	0.31	0.101
E 2	Clay Loam	6.36	1.47	0.46	0.093
E 3	Clay Loam	6.86	1.66	0.39	0.103
E 4	Loamy	6.05	1.58	0.31	0.098
E 5	Loamy	6.39	1.44	0.27	0.103
Average		6.39	1.47	0.35	0.100

According to this, the highest total N content was determined at D location (Average 0.084%) and the lowest total N content at A location (Average 0.066%). Inadequate nitrogen levels in the soil cause weakness of the chestnut and decrease in flowering (Rutter et al. 1990). The available P contents were obtained range from 8.7 to 12.4 mg kg^{-1} in orchard soils. According to the available P contents, 44% of the orchards soils were determined at the limit value and above the limit value (10.5 mg kg^{-1}). The highest P content was recorded as average 10.9 and 10.8 mg kg^{-1} at C and D locations, respectively. The lowest available P content was recorded at the location A (Average 9.8 mg kg^{-1}). It is reported that low phosphorus levels caused a decrease in the number of female flowers (Rutter et al. 1990). According to this, the highest K content was found in the C location (Average 148 mg kg^{-1}) and the lowest in B (Average 124 mg kg^{-1}). In all sampling locations, K contents were recorded above the limit value (100

Table 3. Macronutrient concentrations of soil in sampling orchards

Locations	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})
A 1	0.062	10.7	138.0	211.8	35.1
A 2	0.058	8.7	114.5	223.5	34.3
A 3	0.065	8.8	115.2	131.5	31.9
A 4	0.079	9.4	122.4	156.6	26.5
A 5	0.064	8.3	164.4	235.3	39.1
Average	0.066	9.8	130.9	191.7	33.4
B 1	0.089	10.2	127.3	164.5	27.5
B 2	0.065	8.9	117.7	183.2	29.5
B 3	0.077	10.4	124.6	216.3	35.1
B 4	0.075	10.7	131.2	193.4	32.1
B 5	0.081	10.0	119.3	158.1	27.1
Average	0.077	10.0	124.0	183.1	30.2
C 1	0.069	11.4	138.4	131.4	21.9
C 2	0.074	10.2	132.5	177.6	29.6
C 3	0.082	10.6	166.4	227.4	37.8
C 4	0.073	9.8	147.4	297.6	39.6
C 5	0.075	12.3	155.3	127.9	31.3
Average	0.075	10.9	148.0	192.4	32.1
D 1	0.092	11.4	136.5	281.1	45.8
D 2	0.095	10.5	126.4	261.4	43.2
D 3	0.078	12.4	151.4	252.9	42.0
D 4	0.085	9.2	112.6	198.9	33.2
D 5	0.072	10.4	125.5	164.6	28.2
Average	0.084	10.8	130.4	231.8	38.5
E 1	0.065	9.8	137.4	181.1	30.2
E 2	0.064	12.4	148.5	235.9	38.5
E 3	0.074	8.9	116.9	210.3	34.7
E 4	0.078	9.8	127.4	181.1	30.3
E 5	0.075	10.8	131.4	151.0	27.5
Average	0.071	10.3	132.3	191.9	32.3

mg kg^{-1}). The fertilization program should be started in spring when the development period begins. For a mature chestnut orchard, 112 kg N ha^{-1} is sufficient. Besides, it is recommended to apply 560 kg K2SO$_4$ ha^{-1} potassium fertilizer application to hectare to meet the K needs of plants (Vossen 2000). In soil analysis, Ca values of soils were determined below the limit value (<1150 mg kg^{-1}) parallel to the lime content. The highest Ca content was recorded at the location D (Average 231.8 mg kg^{-1}) and the lowest Ca content at A location (Average 191.7 mg kg^{-1}). Mg contents of soils were determined below the limit value (<50 mg kg^{-1}). The highest Mg content was recorded at D (Average 38.5 mg kg^{-1}) and the lowest Mg content was recorded at B location (Average 30.2 mg kg^{-1}). In rainy regions, calcium and magnesium minerals in the main rock insufficient and coarse-textured soils have low Ca and Mg contents (Kacar and Katkat 1998).

Table 4. Micronutrient concentrations of soil in sampling orchards

Locations	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
A 1	5.41	0.61	62.8	0.87
A 2	4.23	0.53	72.4	1.10
A 3	5.75	0.74	63.4	0.87
A 4	5.06	1.08	58.3	0.75
A 5	5.22	0.89	61.9	0.94
Average	5.13	0.77	63.7	0.91
B 1	5.24	0.71	61.2	1.08
B 2	4.33	0.84	51.2	0.84
B 3	4.51	1.05	54.3	0.76
B 4	3.57	0.98	68.2	1.03
B 5	3.72	1.08	76.4	1.15
Average	4.27	0.93	62.2	0.97
C 1	3.73	0.91	75.5	1.06
C 2	4.61	0.85	53.6	0.82
C 3	4.24	0.73	53.2	0.76
C 4	5.46	0.87	61.5	0.93
C 5	5.08	0.68	85.4	1.03
Average	4.62	0.81	65.8	0.92
D 1	5.44	1.03	61.3	0.94
D 2	4.47	1.12	52.6	0.87
D 3	5.04	1.28	59.6	0.93
D 4	5.23	0.87	58.1	0.91
D 5	4.51	0.92	53.3	1.06
Average	4.95	1.04	57.0	0.94
E 1	4.61	1.12	54.3	0.98
E 2	5.25	1.06	62.4	1.13
E 3	3.18	0.97	61.9	0.85
E 4	4.91	1.06	57.7	1.19
E 5	3.52	1.13	75.1	1.05
Average	4.29	1.04	62.3	1.04

The micronutrient status of soils

According to soil analysis, micronutrient contents are presented in Table 4. The Fe content of 54% of the soils was above the sufficient limit (> 4.5 mg kg^{-1}) and 46% was found at the medium limit (0.2-4.45 mg kg^{-1}). The highest Fe content of the soils was recorded at location A (Average 5.1 mg kg^{-1}) and the lowest at location B (Average 4.2 mg kg^{-1}).

Table 5. Macronutrient concentrations of leaf in sampling orchards (Average of 2012 and 2013)

Locations	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
A1	2.04	0.26	1.29	0.52	0.38
A2	2.12	0.18	1.18	0.46	0.31
A3	1.82	0.21	1.31	0.41	0.37
A4	2.21	0.31	1.27	0.61	0.45
A5	2.09	0.18	1.16	0.55	0.34
Average	2.06	0.23	1.24	0.51	0.37
B1	2.09	0.35	1.64	0.63	0.31
B2	1.82	0.19	1.16	0.78	0.49
B3	2.16	0.22	1.23	0.67	0.43
B4	2.10	0.28	1.21	0.71	0.37
B5	2.27	0.18	1.34	0.67	0.55
Average	2.09	0.24	1.32	0.69	0.43
C1	1.93	0.37	1.12	0.61	0.52
C2	2.07	0.16	1.21	0.58	0.49
C3	2.12	0.19	1.41	0.71	0.37
C4	2.03	0.21	1.38	0.53	0.47
C5	2.11	0.18	1.52	0.49	0.36
Average	2.05	0.22	1.33	0.58	0.44
D1	2.28	0.16	1.37	0.58	0.37
D2	2.06	0.29	1.68	0.51	0.31
D3	2.11	0.33	1.74	0.48	0.29
D4	2.31	0.30	1.36	0.67	0.31
D5	2.02	0.19	1.55	0.84	0.48
Average	2.16	0.25	1.54	0.62	0.35
E1	1.92	0.28	1.60	0.67	0.64
E2	2.09	0.17	1.38	0.58	0.31
E3	2.07	0.15	1.19	0.53	0.42
E4	2.18	0.31	1.21	0.48	0.34
E5	2.10	0.23	1.32	0.51	0.41
Average	2.07	0.23	1.34	0.55	0.42

The Zn content of the orchards soils remained within the limit values (0.5-2.4 mg kg^{-1}). The highest Zn content was found in the D location (Average 1.07 mg kg^{-1}) and the lowest Zn content was recorded in the location A (Average 0.77 mg kg^{-1}). The contents of Cu were found to be sufficient (> 0.2 mg kg^{-1}) in orchards soils, while the contents of Mn were determined above the limit value (14-50 mg kg^{-1}). The highest Cu and Mn contents were recorded at E and C locations (Average 1.04 and 65.8 mg kg^{-1}), respectively. Toprak and Seferoglu (2013) determined the Fe, Zn, Mn, and Cu contents of soils the ranged 3.74-5.72, 0.48-1.62, 0.60-1.43 and 1.49-2.85 mg kg $^{-1}$, respectively in chestnut orchards in Kosk district of Aydın province.

Table 6. Micronutrient concentrations of leaf in sampling orchards (Average of 2012 and 2013)

Locations	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
A1	112.8	30.5	652.2	5.16
A2	108.4	26.2	832.4	6.18
A3	121.8	37.0	748.5	5.21
A4	104.6	54.1	820.3	5.83
A5	118.4	44.6	656.7	5.37
Average	113.2	38.5	742.0	5.55
B1	118.4	35.6	626.6	5.21
B2	119.5	42.2	642.7	4.87
B3	103.7	52.5	764.1	5.37
B4	93.8	49.3	706.2	4.92
B5	107.1	54.6	782.0	5.61
Average	108.5	46.8	704.3	5.20
C1	106.8	45.6	672.1	6.12
C2	105.6	42.8	630.5	5.72
C3	118.2	36.5	620.2	4.87
C4	121.2	43.3	646.0	5.31
C5	105.0	34.2	564.8	4.92
Average	111.4	40.5	626.7	5.39
D1	123.0	51.5	762.1	5.48
D2	103.1	56.0	824.0	5.10
D3	114.4	64.1	746.5	4.89
D4	108.5	44.6	642.8	5.19
D5	104.7	46.0	682.6	5.16
Average	110.7	52.4	731.6	5.16
E1	97.4	56.1	826.5	4.86
E2	108.4	46.8	670.0	5.58
E3	125.3	48.5	736.6	5.13
E4	102.7	54.0	782.2	5.84
E5	114.6	58.2	834.3	6.05
Average	109.7	52.7	769.9	5.49

The macronutrient status of plant

The macronutrient concentrations of leaves are shown in Table 5. According to the results of the analysis, the foliar N concentrations were determined between 1.82 and 2.82%. The highest leaf N concentration was recorded at D location (Average 2.16%) and the lowest at B location (Average 2.05%). The chestnut foliar N concentrations were found between 1.5 and 3.0% in various studies (Arrobas et al. 2017; Toprak and Seferoglu 2013). Chestnut trees averaged 2.38% and 2.41% foliar N when an annual application of 140 or 168 kg ha^{-1} to soil-applied N was applied and a nut yield response was recorded (Warmund 2018).

The foliar P concentrations ranged from 0.15 to 0.37%. The highest and lowest foliar P concentrations were determined at D and B locations (Average 0.25 and 0.22%), respectively. In their study, some researchers (Arrobas et al. 2017) were determined the foliar P concentrations between 0.10 and 0.25%, while some researchers (Toprak and Seferoglu 2013) were found between 0.14 and 0.19%.

The highest foliar K content was recorded at D location (Average 1.54%) and the lowest at A location (Average 1.24%). These values were above the limit value (11 g kg-1 or/ 1.1%) for the chestnut foliar K concentration indicated by Arrobas et al. (2017). Although the foliar K concentration in European chestnut and other nut trees is 2.1-2.2% (Toprak and Seferoglu 2013), it has low K concentrations (0.5-0.6%) due to the lack of application of fertilization in trees grown in Missouri (Warmund 2018). The foliar Ca concentrations directly was affected by the low Ca content of the soil. The Ca concentrations ranged from 0.41 to 0.84%. The limit values of leaf Ca concentration were determined as 1.0% and 1.0-2.5% in some hard-shell nuts such as walnuts and hazelnuts, respectively (Kacar and Katkat 1998). The foliar Ca content was recorded at the highest location C (Average 0.69%) and lowest at location A (Average 0.51%).

The micronutrient status of plant

Micronutrient levels in leaves were also investigated in the chestnut orchards for two years. The amounts of micronutrient in chestnut leaves are presented in Table 6. The foliar Fe concentrations ranged from 93.8 to 125.3 mg kg^{-1}. The highest Fe content was recorded at the location A (Average 113.2 mg kg^{-1}) and at the lowest location C (Average 108.5 mg kg^{-1}). The limit values of foliar Fe concentration were determined as 50-350 mg kg^{-1} in some hard-shell nuts such as hazelnuts (Kacar and Katkat 1998). Toprak and Seferoglu (2013), in their study on chestnut nutrition, found that foliar Fe concentrations were between 197-271 mg kg^{-1}.

The highest Zn concentration was recorded as 52.4 and 52.7 mg kg^{-1} in D and E locations, respectively. The lowest leaf Zn content was determined at the location A (Average 0.77 mg kg^{-1}). In their study, some researchers (Arrobas et al. 2017) were determined the foliar Zn concentrations between 20 and 50 mg kg^{-1}, while some researchers (Toprak and Seferoglu 2013) were found between 34 and 60 mg kg^{-1}. The limit values of foliar Zn concentration were determined as 22-25 mg kg^{-1} and 15-80 mg kg^{-1} in some hard-shell nuts such as walnuts and hazelnuts, respectively (Kacar and Katkat 1998).

In all locations, leaf Mn concentrations were determined above the limit values determined by the researchers (Arrobas et al. 2017). The foliar Mn content ranged from 564.8 to 834.3 mg kg^{-1} in chestnut orchards. In other hard-shelled nuts, leaf Mn contents are for example 30-300 mg kg^{-1} for walnuts and 25-500 mg kg^{-1} for nuts (Kacar and Katkat 1998). The Cu concentrations in the plant were determined between 4.86 and 6.18 mg kg^{-1} in this study. In different studies, these values were determined as 4-50 mg kg^{-1} for hazelnuts and 4-20 mg kg^{-1} for walnuts (Kacar and Katkat 1998). In another study, the Cu contents of chestnut plants were determined between 16 and 24 mg kg^{-1} (Toprak and Seferoglu 2013).

Conclusions

The soil of chestnut orchards examined within the scope of the research is either insufficient or limited by macro nutrients. All the orchards are inadequate for total N, organic matter, lime and therefore Ca and Mg. Although the existing P and K contents seem to be sufficient, fertilization should be done in terms of flowering and fruit quality. Micro nutrients are sufficient in orchards. This situation continued in the same way in plant analysis. As in all cultivated plants, a fertilization program is necessary for the chestnut. However, important decisions should be taken to increase the amount of organic matter in the soil. In addition, Ca content fertilizers should be added to the fertilization program for the plant to be resistant to diseases.

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Morphological characteristics of some *Salvia* L. taxa in Sakarya Province (Turkey)

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Abstract
In this study, morphological characteristics of five *Salvia* L. taxa (*S. verticillata* L. subsp. *amasiaca* (Freyn & Bornm.) Bornm., *S. tomentosa* Mill., *S. virgata* Jacq., *S. forskahlei* L. and *S. sclarea* L.) collected from Geyve, Taraklı, Akyazı and Sapanca districts of Sakarya Province were studied comparatively. Root, stem, leaf, flower and seed characteristics were determined and detailed morphological measurements were made on these organs. It was observed that the morphological findings were highly consistent with the previous studies, but some deviations were observed at the minimum and maximum limits of the measurement values.

Keywords: *Salvia*, morphology, Sakarya, Turkey.

Özet
Bu çalışmada Sakarya ili Geyve, Taraklı, Akyazı ve Sapanca ilçelerinden toplanan beş *Salvia* L. taksonunun (*S. verticillata* L. subsp. *amasiaca* (Freyn & Bornm.) Bornm., *S. tomentosa* Mill., *S. virgata* Jacq., *S. forskahlei* L. ve *S. sclarea* L.) morfolojik özellikleri karşılaştırmalı olarak incelenmiştir. Bu taksonların; kök, gövde, yaprak, çiçek ve tohum özellikleri belirlenmiş ve bu organlar üzerinde detaylı morfolojik ölçümler yapılmıştır. Elde edilen morfolojik bulgular daha önce yapılan çalışmalarla karşılaştırıldığında, morfolojik karakterlerin benzerlik gösterdiği, fakat ölçüm değerlerinin minimum ve maksimum sınırlarında bazı sapmalar olduğu gözlenmiştir.

Anahtar kelimeler: *Salvia*, morfoloji, Sakarya, Türkiye.

INTRODUCTION

The *Salvia* L. genus known as ‘sage’ is one of the richest species of Lamiaceae family. Many wild sage species were used to treat various diseaes consciously or unconsciously since ancient times, this genus has been named *Salvia* derived from the word Salvere which means ‘to be healthy’ in Latin language (Baytop 1999). *Salvia* has 986 species in the world (www.theplantlist.org 2019). In Turkey, identified as 87 species in Flora of Turkey and were recorded as 50% of these are endemic (Davis 1982, Güner et all. 2000). According to the latest studies in our country, *Salvia* species number is 99 and total of 106 taxa are 58 endemic (Güner et all. 2012).

Sakarya and its environs, which we have chosen as the study area, are in A3 square in European-Syberia Phytogeographical Region according to grid system applied by Davis (Davis 1965).

Salvia, which is thought to have originated from Anatolia and Southern Europe, is widespread in Mediterranean countries. They are very resistant to cold and drought and show better development in calcareous and sandy soils (Baydar 2005). *Salvia* taxa in Turkey can live in a wide range of habitats, from sea level to about 3500 m, such as steppe, rocky areas, scrub, forest, meadows, bushes, dunes, roadside slopes, gypsiferous areas, serpentine areas and alpine zones (Karabacak 2009). *Salvia* is a valuable essential oil, spice and tea plant. It is used frequently in perfumery and pharmaceutical industry due to its essential oils. The composition of these essential oils include cineol, thujone, camphor and linalyl acetate (Baydar 2005). *Salvia* species are known with different names such as adacayi, salba, calba, dadirak and kizillik in Turkish (Baytop 1999). The infusion of stem or the essential oil of *Salvia* is used to treat colds, cough, gingivitis, toothache, sore throat, diabetes, high blood pressure, stomach and abdominal pain, rheumatism and skin diseases. It is also used as vasoconstrictor, expectorant and sedative (Skoula 1999).

S. tomentosa (large flowering sage) leaves are used as medical sage (Baytop 1999). Leafy branches are collected and exported to abroad after drying (Baydar 2005). *S. virgata* is known as friar's cowl or larus and its leaves are used topically as wound healing (Baytop 1999, Baytop 1963). *S. forskahlei* is known as chalba and fresh leaves were used to make stuffed meat (Baytop 1999). *S. sclarea* is known as bear ear, musk sage or woolly sage. Flowering branches contain tannin, resin, essential oil and bitter matter. Flowering branches or leaves are used as sedating and reducing perspiration, also used as a 5% infusion in the treatment of costiveness and stomach diseases (Baytop 1999, Baytop 1963). Moreover it is used as perfume raw material and has economic value (Baydar 2005).

Salvia species are usually composed of perennial, herbaceous, semi-shrubby or shrubby plants and leaves, calyx and hair on the flower are important characteristics used to distinguish species (Davis 1982). Also in the revision studies on *Salvia*; morphological features such as stamen type, verticillaster number, calyx shape, corolla shape, corolla length, length of the corolla tube, whether or not annulus or upper lip is flat or helmet shaped, are distinctive characters in the determination of species (Karabacak 2009 and Doğan et all. 2008).

MATERIALS AND METHODS

This study was carried out on *Salvia* populations collected from Geyve, Tarakli, Akyazi and Sapanca districts of Sakarya between the years of 2016-2017. Plant collection was conducted between May and September, the flowering periods of the *Salvia*. The collected plants were prepared as herbarium specimens and morphological features such as location, habitat, vegetation type, altitude, flower color and stem branching shape were recorded. The collected specimens are housed in the Herbarium of the Faculty of Forestry, Duzce University (DUOF). Davis's Flora of Turkey is used in the determination of species (Davis 1982). General morphological measurements were made in 10 plants taken for each taxon and visible morphological characters were recorded. The flower morphology was made on a total of 50 flowers, 5 flowers on each plant. Plant height (cm) was measured from the bottom (under the ground part) to the top of the plant. Stem thickness (cm), measured as a diameter of the main stem 10 cm above the soil surface. The verticillasters on the main stem and side branches were counted seperately and averaged. Leaf measurements (cm), the largest and the smallest leaves on the plant were measured and averaged. Calyx tooth length (cm), the length of the longest teeth were measured. The analysis of the measured values was made in Microsoft Excel.

RESULTS

Salvia verticillata L. subsp. *amasiaca* (Freyn & Bornm.) Bornm.

Plant 56-76.5 cm, perennial, semi bushy, dense secretion and cover hairy (Table 2,3). **Root** 6.5-16 cm, main root is long taproot, side roots available. **Stem** 45-62.5 x 0.3-0.4 cm, upright or elevated, four cornered, usually multiple and branched above (Table 1). **Leaves** 2.5-8.2 x 0.9-5.4 cm, simple, oblong, elliptic or ovate-oblong or unequal lobular lyrate, acute on the top, acuminate, round or semi-cordate on the base, edges are serrate, leaf surface cover and gland hairy. **Petiole** between 0.3-6 cm. **Inflorosens** paniculate, **Verticillasters** 2-46 flowered, 1-7 on a branch, 0.6-4.7 cm very distinctly spaced. **Pedicel** 0.3-0.6 cm. **Calyx** 0.45-0.65 cm, tubular, dark violet-purple color, longer and thicker in the fruit, outher cover hairy, two-lipped, upper lip is shorter than the lower lip and three teeth, lower lip has two teeth, **Calyx teeth** 0.05-0.15 cm, longer on the fruit. **Corolla** 0.8-1.2 cm, light purple, purple, lilac colored, two-lipped, flat on the upper lip and narrows at the base, lower lip is 3 lobed, corolla tube is flat, annulus available, **Labellum width** 0.2-0.35 cm. **Pistil** 0.8-1.2 cm, **Stamens** C type, lower theca reduced, subulate, **Filaments** 0.15-0.4 cm, **Anther** 0.1-0.15 cm. **Bracts** 0.8-5 x 0.35-2.7 cm, ovate-acuminate. **Bracteoles** 0.4-0.9 x 0.2-0.4 cm. **Seeds** 0.15 x 0.1 cm, oval, dark brown or black.

Table 1. Comparison of morphological characteristics on *Salvia* species.

		S. verticillata* subsp. *amasiaca	***S. tomentosa***	***S. virgate***	***S. forskahlei***	***S. sclarea***
STEM	**Stem type**	Upright or elevated	Upright or elevated	Upright	Upright	Upright
LEAF	**Leaf type**	Simple or lyrate	Simple	Simple	Simple or lyrate	Simple
	Leaf shapes	Oblong, elliptic or ovate-oblong	Oblong, elliptic, ovate	Ovate, wider ovate	Elliptic, ovate, wider ovate, sometimes cordate	wider ovate, cordate
	Leaf tip	Acute, acuminate	Acuminate, acute	Acute	Acute, obtuse	Acute, acuminate, obtuse
	Leaf side	Serrate	Crenate, dentate	Irregular lobed erose-crenate	Crenate, undulate	Crenate-erose, dentate, mostly irregular lobed
	Leaf base	Round or semi-cordate	Rotundate, rotundate-truncate	Rotundate or cordate	Rotundate or cordate	Rotundate, cordate, cordate-truncate
BRACT	**Bract color**	Green	Green	Green	Green	White, pink or light purple
	Bract type	Ovate-acuminate	Ovate or wider ovate	Ovate-acuminate	Ovate or wider ovate	Ovate-acuminate
CALYX	**Calyx color**	Dark violet-purple	Green-dark violet	Greenish lilac	Green or lower part greenish, upward violet	Green
	Calyx type	Tubular	Tubular	Tubular - campanulate	Ovate- campanulate	Ovate- campanulate
COROLLA	**Corolla color**	Light purple, purple, lilac	Lilac, purple or pinkish	Lilac-purple, rarely white	Violet-purple, lilac	White or lilac-purple
	Upper lip	Flat and narrows at the base	Flat	Falcate	Falcate	Falcate
	Corolla tube	Flat	Flat	Ventricose	Curved upward	Ventricose
STAMEN	**Stamen type**	C type	A type	B type	B type	B type
SEED	**Seed shape**	Oval	Oval, triangular	Oval	Oval, triangular	Oval, triangular
	Seed color	Dark brown or black	Dark brown or black	Dark brown or black	Dark brown or black	Dark brown

Flowering period: June- August; **Habitat:** Sub-forest, meadow, roadside, lake surroundings; **Altitude**: 448 m; **Location:** Sakarya Taraklı Taraklı-Gölpazarı road Hacıaliler village road turnout, 200 m Taraklı Kayaboğazı pond; **Date of collection:** 18/VI/2016; **Herbarium number:** DUOF 8785. The general view of the taxa is given below (Image 1).

Image 1. General view of *Salvia verticillata* subsp. *Amasiaca.*

Table 2. Comparison of morphological measurements on *Salvia* species

	Characteristics **Min. - Max. (cm)**	***S. verticillata* subsp. *amasiaca***	***S. tomentosa***	***S. virgata***	***S. forskahlei***	***S. sclarea***
PLANT	Plant length	56-76.5	55-90	32.5-91.5	36-93	85-135
ROOT	Root length	6.5-16	12-27	3-24.5	9-25	24-37.5
STEM	Stem length	45-62.5	41-82	26-78.8	21-85	53.5-104
	Stem width	0.3-0.4	0.2-0.5	0.2-0.5	1.5-3.5	0.5-1
LEAF	Number of leaves	7-12	5-9	5-9	4-11	4-10
	Length of basal leaf	_	_	4.8-13.5	6.2-24.3	_
	Width of basal leaf	_	_	2.1-8.7	3.7-16	_
	Leaf length	2.5-8.2	4.6-11.5	2.4-11.5	2-21.6	5.5-18.2
	Leaf width	0.9-5.4	1.5-4.6	1.1-6	1.1-9.1	3.6-13.5
PETIOLE	Length of basal petiole	_	_	1.3-8.5	4-18.5	_
	Petiole length	0.3-6	0.5-4.3	0.2-5	0.5-7.6	0.9-17
INFLORESCENCE	Number of verticillasters	1-7	2-7	4-20	3-16	3-10
	Internodes length	0.6-4.7	0.7-4.8	0.2-3.4	1.1-4.6	0.5-3.6
	Flower number in a verticillaster	2-46	1-12	3-7	1-10	1-6
FLOWER	Calyx length	0.45-0.65	1.1-1.5	0.5-0.85	0.65-1.1	0.8-1.3
	Length of calyx teeth	0.05-0.15	0.25-0.6	0.15-0.3	0.2-0.4	0.35-0.6
	Pedicel length	0.3-0.6	0.15-0.7	0.1-0.2	0.2-0.6	0.2-0.5
	Corolla length	0.8-1.2	2.2-4	1.2-1.8	1.8-3	1.7-2.4
	Pistil length	0.8-1.2	2.1-3.6	1.2-1.85	2.3-3.3	2.3-3.6
	Filament length	0.15-0.4	0.3-0.55	0.5-0.7	0.6-1.3	0.7-1.8
	Anther length	0.1-0.15	0.2-0.35	0.15-0.25	0.2-0.4	0.2-0.35
	Labellum width	0.2-0.35	0.45-1.2	0.45-0.8	_	0.8-1.3
BRACT	Bract length	0.8-5	1.1-5.8	0.4-5.9	0.4-2.25	1.1-6.3
	Bract width	0.35-2.7	0.7-2.6	0.2-2.9	0.25-1.5	0.9-5.3
BRACTEOLE	Bracteole length	0.4-0.9	0.4-1	0.4-0.9	0.3-0.8	_
	Bracteole width	0.2-0.4	0.3-0.6	0.25-0.55	0.3-0.5	_
SEED	Seed length	0.15	0.2-0.3	0.15-0.2	0.15-0.2	0.25-0.3
	Seed width	0.1	0.15-0.25	0.1-0.15	0.1-0.15	0.2-0.25

Table 3. Comparison of morphological measurements of *Salvia verticillata* subsp. *amasiaca* with previous studies.

	Characteristics Min. - Max. (cm)	**Our results**	**Flora of Turkey (1982) results**	**Doğan et all. (2008) results**	**Karabacak (2009) results**
PLANT	Plant length	56-76.5	*	*	*
ROOT	Root length	6.5-16	*	*	*
STEM	Stem length	45-62.5	15-50	15-50	15-50
	Stem width	0.3-0.4	*	*	*
LEAF	Number of leaves	7-12	*	*	*
	Leaf length	2.5-8.2	2.5-13	2.5-15	2.5-15
	Leaf width	0.9-5.4	2-9	2-9	2-9
	Petiole length	0.3-6	1.5-7	1.5-10	1.5-10
INFLORESCENCE	Number of verticillasters	1-7	*	*	*
	Internodes length	0.6-4.7	*	*	*
	Flower number in a verticillaster	2-46	20-40	8-40	8-40
FLOWER	Calyx length	0.45-0.65	0.5-0.7	0.5-0.7	0.5-0.7
	Length of calyx teeth	0.05-0.15	*	*	*
	Pedicel length	0.3-0.6	0.2-0.8	0.2-0.7	0.2-0.7
	Corolla length	0.8-1.2	1.2	1.2	0.8
	Pistil length	0.8-1.2	*	*	*
	Filament length	0.15-0.4	*	*	*
	Anther length	0.1-0.15	*	*	*
	Labellum width	0.2-0.35	*	*	*
BRACT	Bract length	0.8-5	0.7	0.6	0.6
	Bract width	0.35-2.7	0.3	0.3	0.3
BRACTEOLE	Bracteole length	0.4-0.9	*	*	*
	Bracteole width	0.2-0.4	*	*	*
SEED	Seed length	0.15	0.22	0.22	0.22
	Seed width	0.1	0.13	0.13	0.13

* These data were not recorded in previous studies.

Salvia tomentosa Mill.

Plant 55-90 cm, perennial, semi bushy, dense secretion and cover hairy, clustered (Table 4). **Root** 12-27 cm, main root is long taproot, mostly integrated roots. **Stem** 41-82 x 0.2-0.5 cm, usually multiple, sometimes unique, upright or ascending, quadrangular, usually branched above. **Leaves** simple, 4.6-11.5 x 1.5-4.6 cm, Towards the top, dimensions and stems shrink, oblong, elliptic, ovate, below ones rotundate, rotundate-truncate, upper ones acuminate, acute, side ones sometimes irregular sometimes regular lobed crenate, dentate, leaf surface is covered with glandular and covering hair. **Petiole** between 0.5-4.3 cm. **Inflorosens** paniculate, **Verticillasters** 1-12 flowered, 2-7 on a branch, 0.7-4.8 cm spaced. **Pedicel** 0.15-0.7 cm. **Calyx** 1.1-1.5 cm, green-dark violet colored, tubular, longer in the fruit and pellicular, outher surface covered with glandular and covering hair, two-lipped, lips are equal sized, iki dudaklı, upper lip has three teeth, middle tooth is shorter than others, lower lip has two teeth. **Calyx teeth** 0.25-0.6 cm, longer on the fruit. **Corolla** 2.2-4 cm, lilac, purple or pinkish, two-lipped, upper lip is flat and two-lobed, lower lip is three-lobed and middle lobe wider, corolla tube is flat. **Labellum width** 0.45-1.2 cm, **Pistil** 2.1-3.6 cm, **Stamens** A type **Filaments** 0.3-0.55 cm, **Anther** 0.2-0.35 cm. **Bracts** 1.1-5.8 x 0.7-2.6 cm, ovate veya wider ovate. **Bracteoles** 0.4-1 x 0.3-0.6 cm. **Seeds** 0.2-0.3 x 0.15-0.25 cm, triagular, oval, dark brown or black.

Table 4. Morphological measurements of *Salvia tomentosa* compared with previous studies.

	Characteristics Min. - Max. (cm)	**Our results**	**Flora of Turkey (1982) results**	**Doğan et all. (2008) results**	**Karabacak (2009) results**
PLANT	Plant length	55-90	*	*	*
ROOT	Root length	12-27	*	*	*
STEM	Stem length	41-82	<100	<100	30-100
	Stem width	0.2-0.5	*	*	*
LEAF	Number of leaves	5-9	*	*	*
	Leaf length	4.6-11.5	2-11	0.8-11	1.5-12
	Leaf width	1.5-4.6	0.8-5	0.5-6	0.8-5
	Petiole length	0.5-4.3	1.7-5.5	0.8-6	1.8-4.5
INFLORESCENCE	Number of verticillasters	2-7	*	*	6-9
	Internodes length	0.7-4.8	*	*	1-6
	Flowers number in a verticillaster	1-12	4-10	4-10	4-10
FLOWER	Calyx length	1.1-1.5	1.2-1.8	0.7-1.8	1-1.8
	Length of calyx teeth	0.25-0.6	*	*	0.2-0.4
	Pedicel length	0.15-0.7	0.5-1	0.2-1	0.3-1
	Corolla length	2.2-4	2.5-3	2.1-3	2.5-3.5
	Pistil length	2.1-3.6	*	*	*
	Filament length	0.3-0.55	*	*	*
	Anther length	0.2-0.35	*	*	*
	Labellum width	0.45-1.2	*	*	*
BRACT	Bract length	1.1-5.8	0.5-0.8	0.3-2	0.5-1.2
	Bract width	0.7-2.6	0.4-0.8	0.2-1.1	0.4-0.8
BRACTEOLE	Bracteole length	0.4-1	*	*	*
	Bracteole width	0.3-0.6	*	*	*
SEED	Seed length	0.2-0.3	0.35	0.35	0.35
	Seed width	0.15-0.25	0.32	0.32	0.32

* These data were not recorded in previous studies.

Flowering period: April- September; **Habitat:** Lakeside, meadow, roadside, forest; **Altitude**: 1056 m; **Location:** Sakarya Akyazı Dokurcun district 12 km, Sülüklügöl; **Date of collection:** 10/VII/2016; **Herbarium number:** DUOF 8787. The general view of the species is given below (Image 2).

Image 2. General view of *Salvia tomentosa*.

Salvia virgata Jacq.

Plant 32.5-91.5 cm, perennial, semi bushy, dense secretion and cover hairy (Table 5). **Root** 3-24.5 cm, main root is long taproot, side roots are thin. **Stem** 26-78.8 x 0.2-0.5 cm, mostly unique, sometimes multiple, upright, four cornered, moslty branched above. **Leaves** simple, below 4.8-13.5 x 2.1-8.7 cm gathered in the form of rosette shape, on the stem 2.4-11.5 x 1.1-6 cm, towards the top, dimensions and stems shrink, sometimes stemless close to flower, ovate, wider ovate, top of the leaf is acute, leaf sides are irregular lobed erose crenate, leaf floor is rotundate or cordate. Leaf surface covered with covering and glandular hair. **Petiol** between 0.2-8.5 cm. **Inflorescence** paniculate, **Verticillasters** 3-7 flowered, 4-20 on a branch, 0.2-3.4 cm spaced. **Pedicel** 0.1-0.2 cm. **Calyx** 0.5-0.85 cm, greenish violet colored, tubular campanulate, longer and thicker in the fruit, inner and outger surface covered with dense glandular and covering hair, ipper lip is shorter than lower lips and it has three teeth close eachother. Middle tooth is shorter than others, curved backward on the fruit, bisulcate, lower lip has two teeth, **Calyx teeth** 0.15-0.3 cm, longer on the fruit. **Corolla** 1.2-1.8 cm, lilac-purple, lilac colored, rarely white, two-lipped, upper lip is two lobed, falcate, lower lip is three lobed and middle lob is wider, corolla tube is clustered (ventricose), no annulus, **Labellum width** 0.45-0.8 cm, **Pistil** 1.2-1.85 cm. **Stamens** B type, almost the same length on the upper lips, lower theca reduced, **Filaments** 0.5-0.7 cm, **Anther** 0.15-0.25cm. **Bracts** 0.4-5.9 x 0.2-2.9 cm, ovate-acuminate, **Bracteoles** 0.4-0.9 x 0.25-0.55 cm. **Seeds** 0.15-0.2 x 0.1-0.15 cm, dark brown or black, oval.

Table 5. Morphological measurements of *Salvia virgata* compared with previous studies.

Characteristics Min. - Max. (cm)		**Our results**	**Flora of Turkey (1982) results**	**Doğan et all. (2008) results**	**Karabacak (2009) results**
PLANT	Plant length	32.5-91.5	*	*	*
ROOT	Root length	3-24.5	*	*	*
STEM	Stem length	26-78.8	30-100	10-100	20-160
	Stem width	0.2-0.5	*	*	*
LEAF	Number of leaves	5-9	*	*	*
	Leaf length	2.4-13.5	5-30	3.7-30	5-30
	Leaf width	1.1-8.7	2-15	2-15	2-15
	Petiole length	0.2-8.5	1-15	1-15	1-15
INFLORESCENCE	Number of verticillasters	4-20	*	*	*
	Internodes length	0.2-3.4	*	*	*
	Flowers number in a	3-7	2-6	2-6	2-6
FLOWER	Calyx length	0.5-0.85	0.6-1.2	0.5-1.2	0.6-1.2
	Length of calyx teeth	0.15-0.3	*	*	0.4
	Pedicel length	0.1-0.2	0.1-0.25	0.1-0.3	0.1-0.3
	Corolla length	1.2-1.8	1.2-1.5	1.2-2	1.2-1.5
	Pistil length	1.2-1.85	*	*	*
	Filament length	0.5-0.7	*	*	*
	Anther length	0.15-0.25	*	*	*
	Labellum width	0.45-0.8	*	*	*
BRACT	Bract length	0.4-5.9	0.4-0.8	0.2-1	0.4-0.8
	Bract width	0.2-2.9	0.35-0.6	0.2-0.9	0.35-0.6
BRACTEOLE	Bracteole length	0.4-0.9	*	*	*
	Bracteole width	0.25-0.55	*	*	*
SEED	Seed length	0.15-0.2	0.25	0.25	0.25
	Seed width	0.1-0.15	0.2	0.2	0.2

* These data were not recorded in previous studies.

Flowering period: May- September; **Habitat**: Lake surroundings, meadow, roadside, sub-forest; **Altitude**: 1056 m; **Location:** Sakarya Akyazı Dokurcun district 12 km, Sülüklügöl; **Date of collection:** 10/VII/2016; **Herbarium number:** DUOF 8786. The general view of the species is given below (Image 3).

Image 3. General view of *Salvia virgata*.

Salvia forskahlei L.

Plant 36-93 cm, perennial, semi bushy, dense secretion and cover hairy (Table 6), **Root** 9-25 cm, taproot, side roots awailable. **Stem** 21-85 x 1.5-3.5 cm, upright, mostly unique, sometimes multiple, four cornered, usually branched abowe. **Leaves** simple or lyrate, usually gathered in the form of rosette shape at the bottom, 6.2-24.3 x 3.7-16 cm, on the stem 2-21.6 x 1.1-9.1 cm, towards the top, dimensions and stems shrink, elliptic, ovate, wider ovate, sometimes cordate, acute at the top, obtuse, leaf floor is rotundate or cordate, sometimes acute, sides crenate, undulate, leaf surface covered with dense covering and glandular hair, **Petiole** between 0.5-18.5 cm. **Inflorescence** paniculate, **Verticillasters** 1-10 flowered, 3-16 on a branch, 1.1-4.6 cm spaced. **Pedicel** 0.2-0.6 cm. **Calyx** 0.65-1.1 cm, ovate-campanulate, green or greenish underside, dark violet to the top, long and thick in the fruit, , inner and outger surface covered with glandular and covering hair, two-lipped, upper lips is slightly shorter than lower lip and has three teeth, lower lip has two teeth, **Calyx teeth** 0.2-0.4 cm, longer on the fruid. **Corolla** 1.8-3 cm, violet-purple, lilac colored, yellow with white dots, two-liped, upper lip is falcate (helmet shaped) and deep slottet two lobed, lower lip is three lobed, corolla tube is curved upward, no annulus, **Pistil** 2.3-3.3 cm, **Stamens** B type, lower theca reduced, **Filaments** 0.6-1.3 cm, **Anther** 0.2-0.4 cm. **Bracts** 0.4-2.25 x 0.25-1.5 cm, ovate or wider ovate. **Bracteoles** 0.3-0.8 x 0.3-0.5 cm. **Seeds** 0.15-0.2 x 0.1-0.15 cm, oval, triangular, dark brown or black.

Flowering period: May- September; **Habitat**: Creek beds, meadow, roadside, sub-forest, hazelnut grove, light shade and damp places; **Altitude (hight)**: 344 m; **Location:** Sakarya Sapanca Mahmudiye district Dereiçi area; **Date of collection:** 07/VIII/2016; **Herbarium number:** DUOF 8788. The general view of the species is given below (Image 4).

Image 4. General view of *Salvia forskahlei*.

Table 6. Morphological measurements of *Salvia forskahlei* compared with previous studies.

Characteristics Min. - Max. (cm)		**Our results**	**Flora of Turkey (1982) results**	**Doğan et all. (2008) resuts**	**Karabacak (2009) results**
PLANT	Plant length	36-93	*	*	*
ROOT	Root length	9-25	*	*	*
STEM	Stem length	21-85	15-120	15-120	35-120
	Stem width	1.5-3.5	*	*	*
LEAF	Number of leaves	4-11		*	*
	Leaf length	2-24.3	5-30	5-30	8-30
	Leaf width	1.1-16	3-23	3-23	1-23
	Petiole length	0.5-18.5	10-16	10-16	10-16
INFLORESCENCE	Number of verticillasters	3-16	*	*	*
	Internodes length	1.1-4.6	*	*	*
	Flowers number in a	1-10	2-12	2-12	2-12
FLOWER	Calyx length	0.65-1.1	1-1.3	0.8-1.3	0.8-1.3
	Length of calyx teeth	0.2-0.4	*	*	
	Pedicel length	0.2-0.6	0.2-0.5	0.2-0.6	0.2-0.6
	Corolla length	1.8-3	2-3	2-3	2-3
	Pistil length	2.3-3.3	*	*	*
	Filament length	0.6-1.3	*	*	*
	Anther length	0.2-0.4	*	*	*
BRACT	Bract length	0.4-2.25	0.8	0.8	0.8
	Bract width	0.25-1.5	0.6	0.6	0.6
BRACTEOLE	Bracteole length	0.3-0.8	*	*	*
	Bracteole width	0.3-0.5	*	*	*
SEED	Seed length	0.15-0.2	0.2	0.2	0.2
	Seed width	0.1-0.15	0.2	0.2	0.2

* These data were not recorded in previous studies.

***Salvia sclarea* L.**

Plant 85-135 cm, biennial or perennial, semi bushy, rough looking, very dense covering and glandular hair (Table 7), **Root** 24-37.5 cm, main root is long taproot, thin side roots awailable. **Stem** 53.5-104 x 0.5-1 cm, upright, thick, four cornered, moslty unique, çoğunlukla tek, the stem roof is wide, multi branched above. **Leaves** simple, 5.5-18.2 x 3.6-13.5 cm, towards the top, dimensions and stems shrink, wide ovate, cordate, acute on the top, acuminate, obtuse, leaf floor is rotundate, cordate, cordate-truncate, sides crenate-eros, dentate, mostly irregular lobed, leaf surface is covered with glandular and covering hair. **Petiole** between 0.9-17 cm. **Inflorescence** paniculate, **Verticillasters** 1-6 flowered, 3-10 on a branch, 0.5-3.6 cm spaced. **Pedicel** 0.2-0.5 cm. **Calyx** 0.8-1.3 cm, ovate-campanulate, green colored, longer and thick in the fruit, inner and outger surface covered with dense glandular and covering hair, two liped, upper lip is shorter than lower lip, has equal three teeth, sometimes middle tooth is blunt, lower lip has two teeth, **Calyx teeth** 0.35-0.6 cm, longer on the fruid. **Corolla** 1.7-2.4 cm, white, lilac or lilac-purple colored, two-liped, upper lip usually lilac-purple color, two lobed and falcate, lower lip usually cream or white, three lobed, middle lob is wider, corolla tube is clustered (ventricose), squamulate, no annulus, **Labellum width** 0.8-1.3 cm. **Pistil** 2.3-3.6 cm, **Stamens** B type, lower theca reduced, **Filaments** 0.7-1.8 cm, **Anther** 0.2-0.35 cm. **Bracts** 1.1-6.3 x 0.9-5.3 cm, white, pink or light purple shades, exceeding flowers., pellicular, ovate, acuminate. **Seeds** 0.25-0.3 x 0.2-0.25 cm, oval, triangular, dark brown.

Flowering period: May-August; **Habitat**: Sub forest, meadow, roadside; **Altitude**: 415 m; **Location:** Sakarya Taraklı Taraklı- Gölpazarı road; **Date of collection:** 03/VII/2017; **Herbarium number:** DUOF 8782. The general view of the species is given below (Image 5).

Image 5. General view of *Salvia sclarea*.

Table 7. Comparison of morphological measurements of *Salvia sclarea* with previous studies.

Characteristics Min. - Max. (cm)		**Our results**	**Flora of Turkey (1982) results**	**Doğan et all. (2008) results**	**Karabacak (2009) results**
PLANT	Plant length	85-135	*	*	*
ROOT	Root length	24-37.5	*	*	*
STEM	Stem length	53.5-104	<100	<100	<100
	Stem width	0.5-1	*	*	*
LEAF	Number of leaves	4-10	*	*	*
	Leaf length	5.5-18.2	8-14	8-14	8-14
	Leaf width	3.6-13.5	5-10	5-10	5-10
	Petiole length	0.9-17	3-9	3-9	3-9
INFLORESCENCE	Number of verticillasters	3-10	*	*	*
	Internodes length	0.5-3.6	*	*	*
	Flowers number in a	1-6	2-6	2-6	2-6
FLOWER	Calyx length	0.8-1.3	1-1.3	1-1.3	1-1.3
	Length of calyx teeth	0.35-0.6	*	*	*
	Pedicel length	0.2-0.5	0.2-0.3	0.2-0.3	0.2-0.3
	Corolla length	1.7-2.4	2-3	2-3	2-3
	Pistil length	2.3-3.6	*	*	*
	Filament length	0.7-1.8	*	*	*
	Anther length	0.2-0.35	*	*	*
	Labellum width	0.8-1.3	*	*	*
BRACT	Bract length	1.1-6.3	1.5-3.5	1.5-3.5	1.5-3.5
	Bract width	0.9-5.3	1-2.5	1-2.5	1-2.5
SEED	Seed length	0.25-0.3	0.3	0.3	0.3
	Seed width	0.2-0.25	0.2	0.2	0.2

* These data were not recorded in previous studies.

DISCUSSION AND CONCLUSION

In our study on *Salvia* species; important morphological characteristics of plants such as leaf shape, stamen type, calyx and corolla shape, brachial structure and number of flowers in a verticillaster were determined and the required morphological measurements were also compared with each other. In addition, our results were compared with other revision studies on Flora of Turkey and *Salvia* (Davis 1982, Karabacak 2009, Doğan et all. 2008).

The stem of *S. verticillata* subsp. *amasiaca* and *S. tomentosa* are mostly taller and clustered and the stem of other species are upright. *S. sclarea* is rather tall, upright and has thick stem compared to other species. Leaves are usually simple, *S. verticillata* subsp. *amasiaca* and *S. forskahlei* have irregular lobular lyrate leaves alongside simple leaves. Leaf shapes, dimensions, leaf edge, leaf top and leaf base types differ significantly between species. *S. forskahlei* and *S. virgata* have rosette shaped quite large base leaves collected at the base of the stem. The verticillary clusters of flowers have 1-12 flowers, *S. verticillata* subsp. *amasiaca* may have up to 46 flowers. Corolla is single shade such as purple, lilac and violet in all species, whereas in *S. sclarea* species, the upper lip is lilac-purple and the lower lip is white-cream colored. Corolla upper lip can be flat or helmet shaped, (*S. verticillata* subsp. *amasiaca* and *S. tomentosa* have flat upper lip and others have helmet shaped). Corolla tube is with a central design in *S. virgata*, curved up in *S. forshahlei* and flat in other species. Stamens are type C in

S. verticillata subsp. *amasiaca*, type A in *S. tomentosa* and type B in others. Bracts are longer than flowers, have membran structure and they are white, pink or purple colors in *S. sclarea*, it is different from other taxa. Except *S. sclarea* other taxa have bracteoles (Table 1, 2).

It was observed that the morphological characteristics and the measurement values were largely consistent with the data of Flora of Turkey and other *Salvia* revision studies (Davis 1982, Karabacak 2009 and Doğan et all. 2008), but there were some deviations in the minimum and maximum limits of the measurement values . For example, leaf sizes measured smaller than the previous studies while the sizes of the bracts are much larger. Similarly, in our study, it was observed that petioles may be shorter than previous studies and even there are sessile leaves. In this study, more detailed measurements were done on the different parts of plants, especially flower, inflorescence and the distinctive features of the species were more clearly demonstrated (Table 3-7).

The reason of these differences in morphological measurements can be explained by the variation of species, the number of samples examined, altitude and vegetation periods.

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Investigation of natural resilience capacity of soil features affected by low severity ground wildfire after three years in Mediterranean forest ecosystem

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Abstract
Wildfires are one of the succession dynamics in the ecosystem, however forest ecosystems have natural resilience capacity to combat with natural disturbance regimes depend on local ecologic properties. This study was conducted to evaluate natural resilience capacity status of the soil's physical, chemical and hydrological features exposed to low severity ground wildfire after three years in the Bulutoglu village, Kahramanmaras. Particle size distribution, soil reaction (pH), electrical conductivity (EC), organic matter content (OM), dispersion ratio (DR), moisture content (MC), field capacity (FC), colloid/moisture equivalent (CM), particle density (PD), bulk density (BD) and porosity ratio (PR) analysis were performed on two groups of soils (burned and unburned counterpart). The environmental sensitivity index (ESI) include soil, vegetation, climate, and management quality of the study area was determined by MEDALUS methodology. According to the results, there is no environmental sensitivity in the study area. It was determined that the negative effects of soil properties improved significantly after three years from the wildfire except for the PR and BD values. There was no statistically significant difference between the analyzed two soil samples groups. It was concluded that the difference between the bulk density and porosity ratios is not only due to the effects of the fire but also with grazing pressure, especially on the unburned area. According to the results, the burned area suffered from low severity ground wildfire has substantially been naturally rehabilitated itself within three years. Environmentally sensitivity (ESI) of the study area was a play an important role in the recovery of soil features. Additionally recommended avoiding some activities that will compress the soil for increasing natural resilience capacity after a wildfire.

Keywords: Ground wildfire, Soil ecology, Resilience capacity, Fire ecology

INTRODUCTION

Wildfires have occurred in nature since the beginning of life on our planet. Generally all most of all forest fires are caused by human activities (92%) in Turkey (GDF, 2013). Although wildfire is a common disturbance factor in Mediterranean forest ecosystems, wildfires are a part of the ecosystems and secure the sustainability of the ecological cycles (Eiten 1992; Lasanta and Cerdà 2005; Mataix-Solera et al. 2011; Keesstra et al. 2014; Pereira 2015, Verma et al. 2012).

One of the most affected ecological factors is the soil by wildfire. Wildfire can change the soil properties with different degrees. This change in soil properties depends on local conditions such as fire regime (severity, duration and repetition) (Flannigan et al. 2000) and also topography, vegetation or microclimate (Certini 2005).

Changes in the physical and chemical properties of the soil due to destruction of the natural vegetation after forest fires, adversely affect the infiltration ratio, porosity ratio, and water storage capacity (Ferreira et al. 2005; Martin and Moody 2001; Neary et al. 1999). Robichaud (2000) stated that fires can decrease from 10% to 40% soil hydraulic conductivity.

After forest fires, soil organic matter changes as quantity and also affects soil structure with burned and charred materials and erosion (Knicker et al. 2005; Rumpel et al. 2006). Although organic ash deposits occurring immediately after the fire are particularly effective in reducing the surface flow in the hills (Cerda and Doerr 2008), they may reduce the hydraulic conductivity by obstructing the pores in depression areas. Organic matter losses affected other chemical and physical properties such as cation exchange capacities (Ulery et al. 2017) and aggregate stability. Response of aggregate stability to forest fires is complex, there are different opinions about the effect of fire. Because aggregate stability depends on how the organic matter content affects other relevant properties such as soil microbiology, water repellency and soil mineralogy (Mataix et al. 2011).

Scientific studies show that each ecosystem has its own “fire regime”. Fuel accumulation ratio is also an important factor in the wildfire. Especially in the Mediterranean Basin where the potential fuel accumulation ratio is greater than the ratio of decomposition. It has been determined that plants develop adaptability capabilities to survive after wildfire (Kalabokidis 1999; Christensen 1994; Pausas and Vallejo 1999; Neyiyci 1988; Tavsanoglu 2009). Monitoring the changes in health indicators in forest soil after the wildfire is important as it can create data set in functional forest management plans as well as reclamation works in burned areas.

Understanding how the natural resilience power of the soil develops could give us an idea about the adaptation capacity of the ecosystem to wildfires. This study was carried out in the burned and unburned of the forests of Bulutoglu village, Kahramanmaras in order to reveal the change and temporal effects of low severity ground wildfire on some physical, chemical and hydrological properties of soil after three years in Mediterranean forest ecosystems.

MATERIALS AND METHOD

The research area is located around Bulutoğlu village Kel Ahmet Hill, on section 152 of Cinarpinar Forest Sub-district Directorate and it is 5 km away from the nearest settlement (Figure 1). The coordinates of the starting point of the fire is 37° 42’ 13’’ North latitudes – 36° 50’ 11’’ East longitudes. Average slope is 60%, altitude is 721 m and the predominant aspect is west of the study area. Study area size is 2.6 ha (burned area: 1.3 ha, unburned area: 1.3ha).

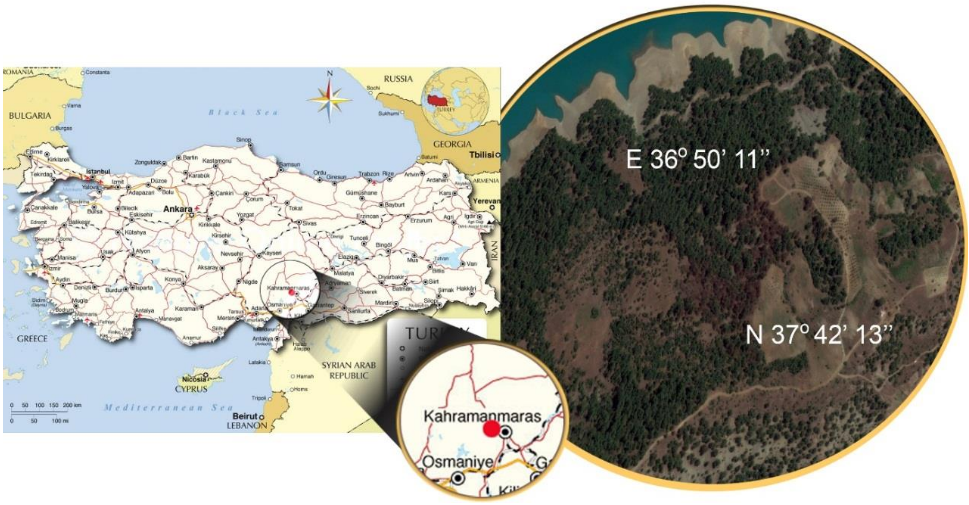

Figure 1. Location of the study area

Evaluation of severity of the fire

Fire severity is defined as the heat energy released by a fire in a unit of time. The severity of forest fires may vary from 20 kW/m to 100,000 kW/m, and >4000 kW/m is accepted as the upper limit for ecological effects (Bilgili 2014). In the research area, some tree deaths occurred in areas where fires were dominant and progressed with low-severity and slowly. It was intervened to the fire directly. It was obtained from post-fire records of the official documents that it had been a level 2 (10-500 ° C) ground fires. The effects of the low severity ground wildfire can be seen on the Google Earth images examined before and after the fire (Figure 2).

Figure 2. The study area before (2011) and after (2014) the wildfire (Google Earth, 2018)

The relative humidity of the research area is 18% and average temperature is 25ºC. The lowest average temperature was observed in January with 4.9°C and the highest in August with 28.5°C (DMI 2015).
In the study area the dominant forest stand type is *Pinus brutia*. Furthermore, some of the recorded vegetation types are as; Turkish Red Pine (*Pinus brutia Ten.*), Juniper (*Juniperus spp.*), Oak (*Quercus sp.*), Storax (*Styrax Officinalis)*. In the study area, bedrock is very homogeneous and formed by a Calcium Carbonate.

Method

Soil sampling

The tree species and components are the same and the main species is *Pinus brutia*. No tillage and no reforestation were carried out and no trees were removed from the area after the low severity ground wildfire. The aspect is the same since burned and unburned areas are adjacent and part of the same geomorphology. Soil samples were taken from the same elevations and slopes.. The tree species and components are the same. The views are the same since they are the continuation of the same physiography. Soil samples were taken from the same elevations and slopes. Totally 108 surface soil samples were taken from 0-20 cm depth for analysis (27 disturbed soil and 27 undisturbed soil from each field). The disturbed soils samples depth (0-20 cm) was decided according to the effect of the fire severity after three years in the field survey. Although forest fires are generally effective on the upper horizon of the soil, the effects of the fire results vary depending on the amount of texture, structure and skeletal matter of the soil over many years. Due to the sandy soil in the research area and percolation that occurred in the years after the fire, organic ash could be transported up to 20 cm in the horizon within macro pores in the study area.

Undisturbed soil samples were taken from 0-10 cm depth. Burned and unburned counterpart (control) area is presented in Figure 3.

Figure 3. Research Area (burned and unburned counterpart area)

Determination of environmental sensitivity index (ESI)

Environmental sensitivity to desertification of the study area analyzed and mapped applying DIS4ME. According to the MEDALUS methodology, some ecology parameters were used determination for quality index. Soil texture, drainage conditions, presence of rock fragments, soil depth, slope gradient, slope aspect, and parent material for Soil Quality Index (SQI); mean annual rainfall, slope aspect and aridity index for Climate Quality Index (CQI); vegetation type and plant cover for Vegetation Quality Index (VQI); land use intensity and policy enforcement for Management Quality Index (MQI) used with the following formula (1) (Kosmas et al. 1999). Desertification indicator system for Mediterranean Europe provided by DIS4ME (Desertlink 2004).

$$\mathbf{ESI} = (\mathrm{SQI} \times \mathrm{CQI} \times \mathrm{VQI} \times \mathrm{MQI})^{1/4} \qquad (1)$$

Type of ESI values and ranges of indices were evaluated according to the following classification (Table 1).

Table 1. Types of ESI and ranges of indices in the karst ecosystem (Kosmas et al, 1999)

Type	Subtype	Range of ESI
Critical	C3	>1.53
Critical	C2	1.42-1.53
Critical	C1	1.38-1.41
Fragile	F3	1.33-1.37
Fragile	F2	1.27-1.32
Fragile	F1	1.23-1.26
Potential	P	1.17-1.22
Non affected	N	<1.17

Laboratory analysis

The particle size distribution of soil samples (PSD) was performed according to Bouyoucos hydrometer method (Irmak 1972; Gulcur 1974; Balci 1996). Dispersion ratio (DR) was performed according to Middleton (Ozyuvaci 1971; Balci 1996). The soil reaction (pH) was determined potentiometrically by the digital pH meter instrument in a 1 / 2.5 ratio of soil-pure water solution (Thomas 1996). Electrical conductivity (EC) was measured using EC meter in 1/2.5 ratio of soil-pure water solution (Rhoades 1982). Organic matter (OM) content was determined according to modified Walkley-Black method (Nelson and Sommer 1982). Field capacity (FC) was determined with Soil Moisture Pressure Plate (Gulcur 1974), Bulk density (BD) according to Ozyuvaci (1975), Particle density (PD) was determined by pycnometer method (Lutzh 1947). The porosity ratio (PO) was determined according to formula (1) (Oztan 1980) based on the relationship between BD and PD.

$$PR = (PD - BD)/PD \times 100 \qquad [1]$$

Where;
PR = Pore volume (%),
PD = Particle density (gr/cm^{-3})
BD = Bulk density (gr/cm^{-3})

Colloid / Moisture Equivalent; the amount of clay obtained as a result of mechanical analysis was found by dividing the same soil by the ratio of moisture equivalents (Baver 1956). The Colloid / Moisture Index are assumed to be resistant to erosion if greater than 1.5.

Statistical analyses

All the analyses results were evaluated by using the SPSS statistical software. The t-test and Mann Whitney-U test were used to determine whether there was a difference between the means of the two groups (burned and unburned forest) (SPSS, 2012).

RESULT AND DISCUSSION

Determination of environmental sensitivity index (ESI) of the study area

Finally defined some physical ecologic qualities (SQI **x** CQI **x** VQI **x** MQI) were matched for definition of the ESI. Some local ecological features were used as Table 2.

Table 2. Some features were used for quality indexes

Quality Index	Features	Local values
SQI	Soil Depth	>75cm
	Slope Gradient	Step (18 to 35%)
	Texture	Sandy (SC, SiL, SiCL
	Parent Material	Sandstone, siltstone
	Drainage	Well drained
	Rock Fragment	Stony (20-60%)
CQI	Mean annual rainfall	>650mm
	Slope aspect	N,NW,N (<5%)
	Aridity index	<50
VQI	Vegetation type	Pines
	Plant cover	High (>40%)
MQI	Land use intensity	Low (sustainable)
	Policy enforcement	Complete (>75%)

Finally three subtype of sensitivity score (critical, fragile and potential) ranging from high sensitivity to low sensitivity were evaluated (Table 3).

Table 3. Quality indexes and ESI values

Quality index	**Critical factors,%**	**Quality score**	**Quality class**
SQI	21	1.26	Medium
CQI	0	1	Good
VQI	41	1.33	Medium
MQI	0	1	Good

	Sensitivity index	**Sensitivity score**	**Sensitivity class**
ESI	12	1.14	Area with no environmental sensitivity

Some soil features of the unburned (control) area

Considering the descriptive data from the unburned area which was not damaged by wildfire, the soil was determined to be erosion sensitive (DR >15) sandy loam, sandy clay with an average of porosity ratio was 22% (Table 4). Bulk density average was 1.97 gr/cm3. Fisher and Binkley (2000) states that heavy machines and humans activities are also effect on soil permeability and bulk density (Ampoorter vd., 2007). Average OM content was determined to be 3.86%.

Table 4. The descriptive statistics from of unburned (control) area

	N	Min	Max	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
pH	27	7.19	8.14	7.76	0.05	0.25	0.06	-0.86	0.45	0.03	0.87
EC (mmhos)	27	0.09	0.28	0.17	0.01	0.05	0.00	0.76	0.45	0.07	0.87
MC (%)	27	3.76	6.50	5.04	0.12	0.62	0.39	0.07	0.45	0.30	0.87
Sand (%)	27	56.35	81.77	66.68	1.45	7.54	56.83	0.47	0.45	-0.90	0.87
Silt (%)	27	7.11	21.05	14.31	0.74	3.83	14.69	0.21	0.45	-0.99	0.87
Clay (%)	27	8.59	29.48	19.01	1.04	5.40	29.17	-0.15	0.45	-0.88	0.87
DR (%)	27	10.07	32.43	24.20	1.02	5.33	28.36	-0.66	0.45	1.19	0.87
FC (%)	27	12.96	30.75	24.38	0.75	3.88	15.08	-0.75	0.45	1.46	0.87
CM	27	0.40	1.57	0.79	0.05	0.23	0.06	1.17	0.45	3.69	0.87
FP (%)	27	8.60	19.40	14.16	0.59	3.07	9.42	-0.20	0.45	-0.99	0.87
PD (gcm^{-3})	27	2.37	2.62	2.48	0.01	0.06	0.00	0.06	0.45	-0.36	0.87
PR (%)	27	5.51	46.52	22.52	2.23	11.60	134.66	0.69	0.45	-0.67	0.87
OM (%)	27	1.47	6.40	3.86	0.27	1.41	1.98	0.15	0.45	-0.85	0.87
BD gcm^{-3}	27	1.27	2.66	1.97	0.07	0.36	0.13	-0.02	0.45	-0.18	0.87

EC: Electrical Conductivity, DR: Dispersion Ratio, FC: Field Capacity, CM: Colloid/Moisture equivalent, FP: Fading Point, PD: Partical Density, PR: Porosity Ratio, OM: Organic Materials, BD: Bulk Density, MC: Moisture Content

Some soil properties of burned area

Descriptive statistics analyze results of soil samples affected by low severity surface ground wildfire that have occurred three years ago. The soils' average pH value is 7.78, clay ratio is 18.47%, EC value is 0.16, dispersion ratio is 25.39%, porosity ratio is 39.20% and organic matter (OM) ratio is 3.52% (Table 5). Organic matter, which contributes significantly to surface soil structure and porosity, can be adversely affected by wildfires (Neary et al. 1999). Knicker et al. (2006) reported that wildfires which do not damage the total vegetation lead to a considerable OM increase. In his study OM content was still decreased after three years of the wildfire (from 3.86 to 3.52 %).

After the forest fires, organic ash is formed by the burning of the organic matter on the topsoil. In the study area, organic ash layer depth was ranging between 0-1 mm after three years in the burnt Turkish Red Pine forest. And organic ash was leached into macro pores in the sandy soil (sand ratio is 64.38%) layers in the study area. The depth of the ash cover on the land surface is variable after fires. In California, 70 mm depth was reported in the oak forest (Ulery et al. 1993). Cepel (1998) state that the distribution of the macro pores in the soil directly affects the movement of water and air. Doerr et al. (2006) emphasized that, forest fires affect the conditions of water repellent in the soil. While some of the organic compounds are flying during the fire, other parts leaching in the soil layers and concentrating on the soil particles in the substrates. As a result, the soil which provides faster water saturation, passes to the surface flow. BD values were changed demand on soil texture, organic matter and ash content. After the wildfire, soil texture does not change but organic ash content would increase in the top layer. BD values were ranging 0.51-2.00 g cm^{-3}. Particle density changed between 2.20-2.56 g cm^{-3} in the study area (Table 5).

Table 5. The result of descriptive statistics analyses of burned area

	N	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
pH	27	7.17	8.14	7.78	0.05	0.24	0.06	-0.75	0.45	0.31	0.87
EC (mmhos)	27	0.08	0.26	0.16	0.01	0.04	0.00	0.80	0.45	0.67	0.87
MC (%)	27	3.80	13.20	5.36	0.33	1.70	2.89	3.96	0.45	18.61	0.87
Sand (%)	27	47.79	79.25	64.38	1.83	9.49	89.98	-0.02	0.45	-1.10	0.87
Silt (%)	27	6.29	23.26	17.15	0.80	4.16	17.34	-0.67	0.45	0.07	0.87
Clay (%)	27	8.52	30.44	18.47	1.26	6.53	42.65	0.09	0.45	-1.20	0.87
DR (%)	27	13.49	46.20	25.39	1.45	7.53	56.70	1.24	0.45	2.64	0.87
FC (%)	27	19.90	34.10	25.10	0.62	3.23	10.43	0.68	0.45	0.83	0.87
CM	27	0.38	1.44	0.73	0.05	0.25	0.06	0.90	0.45	1.18	0.87
FP (%)	27	7.90	19.90	13.43	0.67	3.51	12.30	0.20	0.45	-1.39	0.87
PD gcm^{-3}	27	2.20	2.56	2.45	0.01	0.07	0.01	-1.65	0.45	4.45	0.87
PR (%)	27	19.73	79.05	39.20	2.59	13.44	180.72	0.77	0.45	1.47	0.87
OM (%)	27	0.35	9.57	3.52	0.34	1.77	3.14	1.21	0.45	4.43	0.87
BD gcm^{-3}	27	0.51	2.00	1.49	0.06	0.32	0.11	-0.87	0.45	1.68	0.87

EC: Electrical Conductivity, DR: Dispersion Ratio, FC: Field Capacity, CM: Colloid/Moisture equivalent, FP: Fading Point, PD: Particle Density, PR: Porosity Ratio, OM: Organic Materials, BD: Bulk Density, MC: Moisture Content

Comparison of some soil features in burned and unburned counterpart area

In accordance with the structure of the study, t-test was applied in order to compare the two groups (burned and unburned area). Mann Whitney U test was used for comparing the values of PD, OM, CM, DR and MC out of none-normally distribution (Eymen 2007; Hollander & Wolfe 1973). The results of the Mann-Whitney U test are presented in Table 6. It is seen that “p” values for each feature is p>0.05, so there is no significant difference between the compared features after three years from the wildfire.

Table 6. Comparison of the both lands by Mann-Whitney U Test

	MC (%)	**DR (%)**	**PD (gcm^{-3})**	**OM (%)**	**CM**
Mann-Whitney U	329.500	322.000	298.000	305.500	306.000
Wilcoxon W	707.500	700.000	676.000	683.500	684.000
Z	-0.606	-0.735	-1.154	-1.021	-1.013
Asymp. Sig. (2-tailed)	0.545	0.462	0.249	0.307	0.311

MC: Moisture Content, DR: Dispersion Ratio, PD: Particle Density, OM: Organic Matter, CM: Colloid/Moisture equivalent

Eymen (2007) stated that paired sample t-test is the appropriate tool in measuring the two different datasets. There is a significant difference (p <0.05) at silt ratio, PR and BD mean values in the Table 7.

Table 7. T-test Analysis Results of both lands’ averages

	t-test table						
						95% Confidence Intervals of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
pH	-0.327	52	0.745	-0.021	0.066	-0.156	0.112
EC (mmhos)	0.778	52	0.440	0.009	0.012	-0.015	0.034
Sand **(%)**	0.987	52	0.328	2.301	2.331	-2.377	6.980
Silt **(%)**	-2.609	52	0.012	-2.841	1.089	-5.027	-0.655
Clay **(%)**	0.331	52	0.742	0.539	1.630	-2.733	3.812
FC **(%)**	-0.736	52	0.465	-0.715	0.972	-2.665	1.235
FP **(%)**	0.822	52	0.415	0.737	0.896	-1.062	2.536
PR **gcm^{-3}**	-4.921	52	0.000	-18.621	3.784	-26.214	-11.027
BD **gcm^{-3}**	5.141	52	0.000	0.478	0.093	0.291	0.665

EC: Electrical Conductivity, DR: Dispersion Ratio, FC: Field Capacity, FP: Fading Point, PR: Porosity Ratio, BD: Bulk Density

It was observed that burned forest ecosystem recovered itself after 3 years from the low severity ground wildfire occurred in the study area. This recovery processes were affected by fire severity and other ecological conditions (related ESI value). Ecosystem would take a longer to reach a balance based on excessive fire intensity. This study results show that generally some soil features could rehabilitate itself after three years from low severity ground wild fire in area has low ESI value (Figure 4). Bradstock et al. (1995) reported that, a rapid recovery occurred after 4-7 years due to fire intensity after forest fires in the Australian eucalypt-dominated environments. Degraded soil structure after fires can be improved from 1 year to 10 years depending on the ecosystem conditions (Neary et al. 1999).

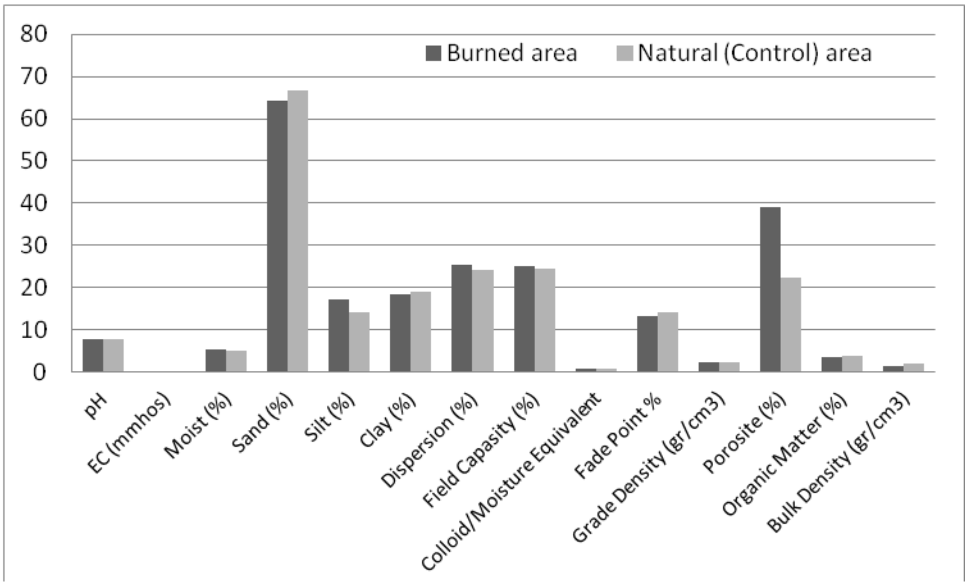

Figure 4. Change of soil features after three years from ground wild fire

Correlation analysis was performed between some soil properties, slope and elevation in the burned and unburned area. It is observed that the sand ratio values have a statistically significant ($p < 0.05$) positive relation with the elevation (Table 8). In cases the value of “p” is less than 0.05 and 0.01, it is accepted that there is a very significant difference between the two groups (Eymen 2007).

There was a statistically significant ($p < 0.05$) negative relationship between CN values and slope. Cepel (1998) emphasized that the change in soil properties in terms of elevation. It was determined that sand fractions were higher, silt and clay fractions were lower, BD and PD have low values as the elevation was increased. Negative significant sensitivity has been determined in the burned area especially in slope with FP, PR, OM and BD values (Table 8). Slope and topography are one of the most fire producers and severity depends on the interactions with other environmental conditions (Dunne and Leopold 1978; Neary et al. 1999). After wildfires, due to the increase in shear stress depending on the slope ratio with the acceleration of surface flow causes the transport of organic matter (Hyde et al. 2007). FP, PR and BD values are affected by OM. After three years of the low severity ground wildfire, the negative effects of the wildfire on the soil began to disappear however the negative effects of physiographic characteristics on the soil are still dominant (Table 8).

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Conclusion

In this research, the natural resilience capacity of the forest ecosystem was evaluated using some soil properties between unburned and burned counterpart area have affected by low severity ground wildfire.

Table 8. Correlations between the burned and unburned area depend on elevation and slope

Pearson Correlation	**Units**	**Unburned**		**Burned**	
Parameters		**Elevation**	**Slope**	**Elevation**	**Slope**
Sand	%	0,437*	0,159	-0,167	0,131
CM		-0,224	-0,390*	0,092	-0,194
FP	%	-0,264	-0,173	0,339	-0,430*
PR	%	-0,074	0,212	0,175	-0,654**
OM	%	-0,034	0,246	0,256	-0,664**
BD	$grcm^{-3}$	0,055	-0,224	-0,147	0,642**

CM: Colloid/Moisture Equivalent, FP: Fading Point, PR: Porosity Ratio, OM: Organic Matter, BD: Bulk Density

*. Correlation is significant at the 0.05 level (2-tailed)., **. Correlation is significant at the 0.01 level (2-tailed).

As a result of the analysis, although there were some differences between the two areas (burned and unburned counterpart) after three years of low-severity ground wildfire in Mediterranean forest ecosystem has no environmental sensitivity (ESI), it was observed that the ecosystem recovered itself in terms of soil properties. The natural resilience processes have affected by microclimate and other micro ecologic conditions. Therefore, subsequent rehabilitation studies will help to shorten the self-resilience period of the ecosystem. As a first improve the degraded soil healthy after wildfire can increase resilience capacity of the ecosystem. Especially should be avoid some activities may reason compact of the soil. If soil tillage is required should be done with manpower. Organic ash that has accumulated in sandy soil after the fire should be distributed homogeneously.

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Evaluation of water quality variables and their effects on fish life in Asarsuyu stream (Düzce/Turkey)

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Abstract

Asarsuyu Stream is one of the tributaries of Melen River located in the Western Black Sea Region in Turkey. It has been exposed to intensive industrial activities as well as agricultural and urban discharges. Ichthyofauna of the stream consists of *Squalius pursakensis*, *Barbus tauricus*, *Alburnoides tzanevi*, *Rhodeus amarus*, *Alburnus derjugini*, *Gobio baliki*, *Cobitis splendens*, *Oxynoemacheilus banarescui*, *Gambusia holbrooki*. In order to associate water quality of Asarsuyu Stream with fish life, we monitored some physical and chemical parameters (i.e. temperature, conductivity, salinity, total dissolved solids, pH, dissolved oxygen, nitrite, nitrate, ammonium, phosphate, sulphate, calcium, magnesium, chloride, sodium and potassium) seasonally during February and November 2018. All of the obtained data were compared according to the criteria of SKKY (Water Pollution Control Regulation in Turkey) and evaluated according to the criteria of European Commission on the quality of fresh waters needing protection or improvement in order to support fish life. Our results suggest that dissolved oxygen may play a critical role in fish survival especially during spring and autumn in the study area. According to the classification criteria for nitrogenous compounds, our monitoring stations ranged from I to IV. Especially nitrite and ammonia have been determined to reach critical levels for fish health. Obtained results can be considered as an indicator of organic pollution in the stream. Therefore, the pollutant sources for stream should be controlled in order to conserve the fish populations in Asarsuyu Stream.

Keywords: Water Quality, monitoring, fish health, Melen River Basin

Introduction

The term water quality refers to as all physical, chemical and biological factors affecting certain use of water. In order to assess the suitability of water for various use, physicochemical factors affecting the quality of water should be known (Boyd and Lichtkoppler 1993). All organisms in the nature are influenced by abiotic factors prevailing in their environment. The main biological functions of organism such as feeding, growth and reproduction are closely related to the physical and chemical properties of the surrounding environment. In order to obtain optimum yield in fish production, the relationships between the environmental conditions and fish should be well known (Boyd and Lichtkoppler 1993). Therefore, information about physical and chemical properties of water are required in fisheries biology studies, in order to determine life-history traits of fish species.

Streams, rivers and their drainage basins are main part of surface water ecosystems. Although rivers and streams constitute an significant amount of the land surface, only 0.0001% of the water of the Earth occurs in river channels. In spite of these low quantities, running waters are of enormous significance to humans (Wetzel 2001). Water is required for drinking and personal hygiene, fisheries, agriculture, industrial production, hydropower generation, recreational activities such as angling. Additionally, water has been considered the most suitable medium to clean, disperse, transport and dispose of wastes (domestic and industrial wastes, mine drainage waters, irrigation returns etc.) since ancient times (Chapman 1992, Svobodá et al 1993; Akman et al. 2000). Water use for different purposes impacts on the quality of the aquatic environment (Zalidis et al. 2002). In addition to intentional water uses, several human activities such as deforestation, accidental release of chemical substances, discharge of untreated wastes, excessive use of fertilizers and pesticides have indirect and undesirable effects on the aquatic environments. Therefore, water quality could be considered a strategic factor for many countries affected by both climate change and rising water-demand.

Water is actually a habitat for millions of microscopic and macroscopic living organisms, in addition to its importance as an essential natural resources. The quality of the aquatic environment can be defined by physical condition and chemical composition of water, as well as the composition and state of aquatic biota found in a water body. The quality of the aquatic environments shows temporal and spatial variations, and it is constantly changing in response to daily, seasonal and climatic rhythms. Organisms, including fish, in a particular water-body can adapt to these natural fluctuations of water quality (including temperature) as they occur (Svobodá et al. 1993). Pollution of the aquatic environments means directly or indirectly introduction of substances or energy, and it results in such deleterious effects as harm to living resources, hazards to human health, prevention to aquatic activities including fisheries and recreation, restriction to its use in agricultural, industrial and often economic activities (Chapman 1992).

Fishes are ecologically and commercially important aquatic animals. In many countries, fish provide inexpensive source of animal protein and other essential nutrients for human health (Rose 2000). Physical and chemical properties of water are important factors which affected physiological functions of fish such as feeding, breeding, digestion and excretion (Bronmark and Hansson 2005). One of the main goal of fisheries management is to provide sustainable utilization of resources. Effective fisheries management to ensure sustainability requires information about abiotic conditions including water quality that affect fish populations (Rose 2000). Fish are very sensitive to changes in environmental quality, especially during early life stages (Nikolsky 1963). Thus, understanding of water quality that affects fish populations is critical for predicting population dynamics and effective management.

Asarsuyu Stream is one of the tributaries of Melen River located in the Western Black Sea Region in Turkey. The Melen River watershed is used to support the water requirement of İstanbul city, However, there are some important pollution source such as domestic, industrial wastewater and agricultural run-off in the basin (Koklu et al. 2010, Akıner and Akkoyunlu 2012). Asarsuyu Stream drainage basin has been influenced by intensive industrial activities and daily residential plants effluents (Koklu et al. 2010). Although some studies have been carried out on the assessment water quality of Melen Basin, no evaluation has been made for ecological impacts of pollution on the aquatic organisms. The objective of the present study is to determine seasonal changes in water quality variables in Asarsuyu Stream and to evaluate their possible impacts on native fish fauna.

Material and Methods

Study Area and Sampling

Asarsuyu Stream is originated from the northwest of the Bolu Mountains and passes through southern to Düzce, joins Küçük Melen River before draining into the Efteni Lake. The length of the stream is 38 km and its catchment area is approximately 180 km² (Anonymus, 2014). Mean flow of the stream ranged between 0.35 m^3/sn and 130 m^3/sn (Anonymus, 2014). Domestic and industrial wastewater effluent is supposed to be the main threats for Asarsuyu Stream (Koklu et al., 2010). According to literature (Anonymus, 2014) and our samplings, ichthyofauna of the stream consists of *Squalius pursakensis*, *Barbus tauricus*, *Alburnoides tzanevi*, *Rhodeus amarus*, *Alburnus derjugini*, *Gobio baliki*, *Cobitis splendens*, *Oxynoemacheilus banarescui* and *Gambusia holbrooki*.

Three sampling points were selected and water samples were collected seasonally between February and November 2018.

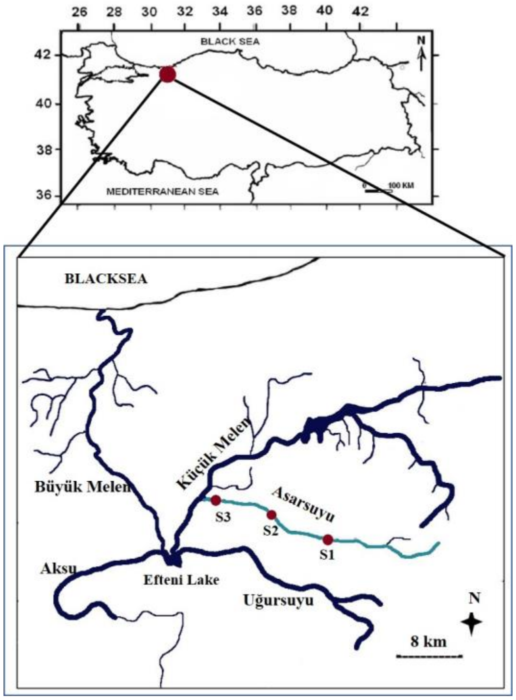

Figure 1. Melen River Basin and sampling stations on Asarsuyu Stream (S1, S2 and S3 stand for sampling points).

The first sampling point (S1) was close upstream, whereas the other sampling points (S2 and S3) were located at downstream and may reflect the urban pollution load of Asarsuyu Stream (Fig. 1 and Table 1).

Table 1. Coordinates and altitude of sampling stations.

Stations	Part of stream	Latitude	Longitude	Altitude (m)
S1	Input of Düzce	40°47'44.90" N	31°14'14.02" E	200
S2	Düzce	40°49'19.70" N	31°11'43.68" E	125
S3	Output of Düzce	40°50'6.67" N	31° 8' 6.11" E	115

Water samples were taken into 1 L polypropylene bottles at each sampling stations, and they were transported to the laboratory in cold chain.

Chemical and Physicochemical Analysis

Physical and chemical parameters of water including temperature (T), electrical conductivity (EC) (25°C), salinity (Sal), total dissolved solids (TDS), dissolved oxygen (DO) and pH were measured in situ using YSI ProPlus Multiparameter water quality meter during field studies. The measurements were carried out once per month from each sampling points.

Chemical analysis were carried out using "IC (Thermo Scientific Dionex ICS 500+)" instrument available in the Scientific and Technical Research Center of Düzce University. Determination of common inorganic anion and cation content of water was achieved by ion chromatography, a widely used environmental monitoring tool. Dionex IonPac AS18-4µm Column and IonPac CS16 Column were used for anion and cation seperation, respectively.

The obtained data were compared with the limit values reported in the Water Pollution Control Regulation in Turkey (SKKY 2004).

Results

Seasonal changes in values of physical and chemical parameters are given in Table 2.

Temperature passed 20˚C in the summer and the maximum value was recorded as 22.8˚C at the S1. The conductivity, salinity, and TDS slightly increased during summer and autumn. Conductivity was over 600 µS/cm during the summer. pH ranged between 7.50 and 8.25 at S1, 7.55 and 8.41 at S2 and 7.73 and 8.98 at S3. During winter period DO was approximately 10 mg/L at all sampling points, however it decreased dramatically in spring and autumn (minimum 4.15 mg/L at S1, 5.88 mg/L at S2 and 4.60 mg/L at S3).

The highest ammonium-nitrogen (NH_4-N) level was recorded at the S1 during the study period (maximum 3.75 mg/L). Nitrite level ranged from 0.36 to 3.16 mg/L during spring, summer and winter, and increased to the highest record in autumn (5.57 mg/L in S1). Nitrate level ranged from 2.50 (Winter, S1) to 7.40 mg/L (Summer; S2). Chloride concentration varied between 33.04 (Autumn; S2) and 38.28 mg/L (Autumn; S1). The sulphate level was lowest in winter, and highest in spring in all sampling points. Ortophosphate concentration cannot be recorded in winter, however, it ranged from 0.02 to 0.26 mg/L during the rest of the study period. were very low at all stations. The highest level of magnesium was 12.73 mg/L at the S3

Table 2. Seasonal changes in water quality parameters (ND: not detected)

Parameters	**Winter**			**Spring**			**Summer**			**Autumn**		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
T (˚C)	7.6	8.3	10.9	13.4	12.7	14.0	22.8	21.7	20.4	16.3	17.3	18.7
EC (25˚C) (µS/cm)	563	567	540	557	567	511	616	601	600	593	594	612
Sal (ppt)	0.27	0.28	0.26	0.27	0.28	0.25	0.30	0.29	0.29	0.29	0.29	0.30
TDS (mg/L)	366	369	351	362	366	332	403	390	390	385	384	397
pH	7.85	7.91	8.74	8.28	8.41	8.98	7.73	7.85	8.08	7.50	7.55	7.73
DO (mg/L)	10.91	10.33	10.49	4.15	6.29	4.60	6.66	8.13	8.06	5.70	5.88	6.66
NH_4-N (mg/L)	3.29	1.01	0.93	3.22	1.52	0.90	3.75	0.30	2.32	3.41	1.86	0.07
NO_2-N (mg/L)	ND	1.82	0.36	ND	0.49	0.69	3.16	2.07	2.55	5.57	5.27	3.97
NO_3-N (mg/L)	2.50	4.00	3.41	2.58	4.07	2.93	2.86	7.40	5.81	2.68	7.36	6.48
Cl (mg/L)	34.38	36.75	34.46	33.17	34.01	33.10	36.48	34.46	34.78	38.28	33.04	34.58
SO_4 (mg/L)	46.01	49.42	45.26	136.5	140.4	143.1	116.7	125.9	122.4	107.5	110.6	112.73
PO_4 (mg/L)	ND	ND	ND	0.06	0.13	0.02	0.26	0.15	0.18	0.10	ND	0.17
Mg (mg/L)	10.43	10.63	10.39	11.39	11.38	11.46	11.59	12.35	11.54	11.23	9.51	12.73
Ca (mg/L)	80.19	81.81	76.95	85.45	87.90	77.38	82.80	88.79	84.53	81.76	86.16	87.72
Na (mg/L)	21.93	23.2	21.13	20.68	20.68	20.49	22.25	23.25	24.46	24.30	23.26	23.93
K (mg/L)	1.94	2.75	2.54	2.09	2.55	2.28	2.69	3.34	3.58	4.45	5.33	3.68

during autumn. Calcium concentration varied between 76.95 and 89.78 mg/L. A slight increase was observed in sodium and potassium levels during summer and autumn.

According to the criteria of Water Pollution Control Regulation in Turkey (SKKY 2004), the monitored stations are classified as I-IV during the monitoring period (Table 3). High ammonium and extreme nitrite concentrations, as well as low dissolved oxygen levels, have caused dramatical decline in water quality. According to SKKY's rule of "The lowest quality class determines the class of the group", Asarsuyu Stream can be considered as Class IV (Very Polluted Water) in terms of Physical and Inorganic Chemical Parameters.

Table 3. Water quality classification of Asarsuyu Stream according to criteria of Water Pollution Control Regulation in Turkey (SKKY, 2004)

Parameters	Sampling Sites		
	S1	**S2**	**S3**
T	I-II	I-II	I-II
TDS	I	I	I
pH	I-II	I-II	I-II
DO	I-III	I-III	I-III
NH_4-N	IV	II	I-II-III
NO_2-N	I-IV	IV	IV
NO_3-N	I	I-II	I-II
Cl	II	II	II
SO_4	I-II	I-II	I-II
Na	I	I	I

Discussion

Water quality is a significant factor for fish life. Feeding, growth and breeding activities of fishes are closely related to the physicochemical properties of the aquatic environment (Nikolsky, 1963). In this study, certain water quality parameters of Asarsuyu Stream were measured in order to evaluate the environmental conditions which affected fish life.

Temperature is a very important parameter for aquatic life since it affects the rate of biochemical reactions and dissolution of gases and changes the viscosity and density of water, as well. The metabolic rates of aquatic organisms, mainly fish, varies with temperature. For example, carp can successfully survive in a wide temperature range, however its feeding (8-10°C) and breeding (15°C) activities occur only at certain temperatures (Nikolsky, 1963). In Asarsuyu Stream, water temperature varied between 7.6°C and 22.8°C. Ichthyfauna of Asarsuyu Stream mainly consists of cyprinid fish. The optimal temperature for feeding of cyprinid fish is 23°C (Svobodá et al 1993), and water temperature in the Asarsuyu Stream is appropriate for native fish fauna.

TDS (total dissolved solids) is referred the quantity of dissolved materials in water, while salinity is defined total amount of salts dissolved in water (Köse et al., 2014). Conductivity is a measure of the ability of water to pass an electrical current, and it is affected by the presence of dissolved solids. TDS and salinity levels in water are closely related to conductivity levels: when the TDS and salinity value in water rise, the conductivity value will also increase, and these parameters considered as an indicator of general water quality (Köse et al., 2014). Sewage wastes and irrigation returns could raise the levels of these parameters because of the presence of chloride, phosphate, and nitrate (Wetzel 2001; Manahan 2011). Inorganic minerals dissolved in water lead to changes in osmotic pressure in aquatic organisms, and many aquatic species cannot resist osmotic pressure changes (Jobling 1995). The ecological stability in the water is disrupted in case EC reaches 3000 µS/cm (Svobodá et al 1993). The EC values of the waters suitable for fisheries are generally ranged between 150 and 170 µS/cm (Bremond and Vuichard 1973). However, obtained TDS values indicated Class I quality of water in Asarsuyu Stream and EC was found between 511 and 616 µS/cm. These are not critical values for native fish fauna. The main reason for the recorded high values of TDS and EC can be considered as runoff from industrial and urban areas in the basin.

Dissolved oxygen is one of the most important parameter for monitoring the water quality (Wetzel 2001). The amount of dissolved oxygen in water depends on the current temperature, density of dissolved salts, and biological processes of the aquatic organisms (Svobodá et al, 1993). Despite the detected high dissolved oxygen levels during the winter, Asarsuyu Stream has low level of oxygen values especially during the spring. Bremond and Vuichard (1973) stated that the minimum concentration of dissolved oxygen required for the survival of Cyprinid fish should be at least 5.0 mg/L. According to the limit values in surface waters for the protection of fish health in European Communities Regulations , measures are required to ensure that the amount of dissolved oxygen does not decrease below 6 mg/L for salmonids and below 4 mg/L for cyprinids (EC 2006). The minimum dissolved oxygen level measured in the Asarsuyu Stream was 4.15 mg/L during spring. The obtained data indicated that oxygen may be a critical factor for fish survival especially during spring and autumn in the study area.

Another chemical parameter affecting aquatic organisms is pH, and it is considered as an indicator of acidity of water. Optimum pH values for many fish species are ranged between 6.5 and 8.5 (Arrignon 1976; Dauba 1981), however pH values >10.8 and <5.0 are lethal for cyprinids, especially carp (Svobodá et al 1993). According to the European Communities Regulations, pH should between 6 and 9 for salmonids and cyprinids (EC 2006). In the present study, pH values ranged from 7.50 and 8.98, and these pH values are appropriate for fish health.

Sulphate is one of the natural anions in water, and its natural sources include gypsum and rain water. The increased amounts of sulphate in aquatic environments due to various industrial, agricultural and domestic wastes are considered as an indicator of pollution. Sulphate concentration exceeding 250 mg/L in water indicates serious contamination (Nisbet and Verneaux 1970). In the present study, sulphate concentrations were found between 45.26 and143.08 mg/L at each observation points. Therefore, the amount of sulphate is not at a level that poses a risk to fish health.

Chloride is an important chemical component of all natural waters and is usually found in very low concentrations. Chloride content varies usually between 10-20 mg/L in freshwater environments (Wetzel, 2001). In Asarsuyu Stream, chloride concentration ranged from 33.04 to 38.28 mg/L which indicated class II water quality in terms of chloride (SKKY 2004). The obtained chloride values seem to be convenient for fish.

Calcium and magnesium ions are among the most abundant components of natural waters. Both calcium and magnesium have important role for primer productivity in aquatic environments. Calcium content in natural waters can reach up to 150 mg/L. When the calcium content is around 25 mg/L, the productivity rate reach the maximum value, and calcium concentrations below 12 mg/L cause decreace in productivity twice (Nisbet and Verneux 1970; Bremond and Vuichard 1973). Magnesium concentration in waters suitable for fisheries should be less than 14 mg/L (Alabaster and Lloyd 1980). In the present study, maximum calcium and magnesium concentrations were found 88.79 mg/L and 12.73 mg/L, respectively. These values seem to be suitable for both optimum productivity of water and fish health.

Phosphate is a limiting factor for primary productivity in aquatic ecosystems (Wetzel, 2001). It is transported to water by decomposition of organic materials, washing of fertilizers used in agriculture, discharge of domestic and industrial wastewaters to aquatic environments. Nisbet and Verneaux (1970) stated that the high primer productivity occurs in waterbodies containing phosphate concentration of 0,15-0,30 mg/L and phosphate levels exceeding 0.30 mg/L are considered polluted water. Excessive pollution and eutrophication occur in aquatic ecosystems when the phosphate content exceeds 0.50 mg/L. Orthophosphate amounts were found varying between 0.02 and 0.26 mg/L in Asarsuyu Stream, and these values seem to be convenient for fish,

The amount of nitrate in surface waters is usually less than 1 mg/L, and rarely up to 5 mg/L (Anonymous 1981). Nitrate salts are important since they encourage the development of algae and green plants, thus provide nutrients and breeding environments for fish such as carp. Although the toxicity of nitrate is low, it has toxic effects for carp when its concentration in water exceeds 80 mg/L (Svobodá, et al., 1993). However, when the nitrate nitrogen in the water exceeds 46 mg/L, methemoglobinemia occurs in fish (Nikolsky 1963). Asarsuyu Stream has class I and II water quality in terms of nitrate (SKKY 2004). Nitrate levels were found between 2.50 and 7.40 mg/L, and these values seems to be convenient for fish, especially cyprinids.

Although surface waters contain ammonia as a result of microbiological activities, ammonia in water can sometimes be an indicator of pollution. According to Nisbet and Verneaux (1970), waters contained ammonium higher than 1 mg/L are considered to be extremely polluted. In the present study, ammonium levels varied between 0.30 and 3.75 mg/L. Extreme ammonia levels were observed especially at S1, and this section of the Asarsuyu Stream is not suitable for fish due to ammonia pollution.

Nitrite is the intermediate product of the nitrogen cycle. In addition to nitrates, nitrites contribute to the development of phytoplankton, and thus primer productivity. Nisbet and Vernaeux (1970) suggests that if the amount of nitrite in the water exceeds 1 mg/L, pollution has started. In the present study, nitrite concentration ranged from 0.36 to 5.57 mg/L. Nitrite levels have peaked especially during summer and autumn, These excessive nitrite levels which indicated the nitrite pollution in water can be considered as a risk to fish health.

In conclusion, dissolved oxygen and nitrogenous compounds, especially nitrite and ammonium, are critical parameters for fish health in Asarsuyu Stream. These results can be considered as an indicator of organic pollution in the river. We can suggest that the pollutant sources for stream should be controlled in order to conserve the fish populations in Asarsuyu Stream.

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Comparison of ASTER, contour lines and LiDAR based DEMs in terms of topographic differences in forested area

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Abstract

DEMs (Digital Elevation Model) generated with different remote sensing techniques and technologies. DEMs are used to determine the changes of vegetation in forests depending on topographical factors. The accuracy of DEMs has a major impact on the planning and management of forests.

In this study, the accuracy of two different DEM data sources, which are frequently used in the modeling of topographic changes in large field studies in forestry, was compared with the LiDAR-based DEM dataset on a forest site. In this context, three different DEM source were used. One of them was the 10 m interval contour lines of 1:25,000 scale aerial photogrammetry based standard topographical maps which are produced by National General Directorate of Mapping. Topomap contour lines are transformed to grid based DEMs by using TIN and ANUDEM based approaches at 2.5, 5, 10 and 30 m resolutions. The other data was ASTER GDEM (1 arc-second ASTER GDEM Version 2, approximately 30 m resolution). The final and reference data is the LiDAR based, 0.25 m resolution DEM. In total, 33 DEM datasets are compared with the LiDAR-based DEM dataset. For these data sets, five difference metrics were calculated: pixel based difference models, the areal and volumetric difference of surface models, the areal difference of slope classes and the areal difference of aspect classes. According to the results of the analysis, the resolution, according to the topographic characteristics of the area and selected interpolation approaches has an effect on DEM modeling and DEM –derived metrics. In addition, the forest structure has a major impact on the accuracy of ASTER GDEM data.

Keywords: DEM, Accuracy, ASTER, Contour line.

Introduction

A digital elevation model (DEM) is a digital representation of the three-dimensional information of the Earth's surface. DEM is generally represented in the digital environment as a raster grid model or a triangular irregular network (TIN) model (Wilson and Gallant, 2000; Li *et al.*, 2005; Li *et al.*, 2017).

Digital elevation model (DEM) is the basis of computer-based topographic modeling and is one of the most important data for terrain-related applications. DEMs are widely applied in the fields of forestry (Aryal *et al.*, 2017; Goodbody *et al.*, 2018), agriculture (Tarolli *et al.*, 2019), hydrology (Beven and Kirkby, 1979; Tarboton, 2003), soil (Blöschl and Sivapalan, 1995; Behrens *et al.*, 2010; Florinsky, 2016; Behrens *et al.*, 2018), landform (Flores-Prieto *et al.*, 2015), military (Talhofer *et al.*, 2015), etc.

Many input data such as biological, sociological, topographic etc. can be used in the managing and planning of forests (Bettinger *et al.*, 2010). One of the most important factor that affects the cost of forestry activities applied in large areas is the accuracy and precision of the data to be used in the planning stage (Duvemo and Lämås, 2006). In this context, it is very important to model the topographical variabilities as accurately as possible, that directly affects forestry activities.

DEMs can be produced using stereo-photogrammetry, field surveys, radar (Radio Detection and Ranging) and LiDAR (Light Detection and Ranging) based techniques and technologies (Fleming *et al.*, 2010). Each of the techniques or technologies has its own pros and cons. Although DEM generation can be accomplished using the methods listed above, contour lines, which are an inexpensive data source for large-area studies, are still used in most countries to generate DEMs (Oky Dicky Ardiansyah and Yokoyama, 2002; Li *et al.*, 2017). A contoured topographic map presents terrain elevation and morphological information with contour lines and is the most common way to represent the terrain (Li *et al.*, 2005). In DEM production based on the contour line, an interpolation technique must be used to model the areas between the lines. From past to present, many interpolation techniques are discussed for DEM generation or 3d surface modelling in literature (Hardy, 1971; Briggs, 1974; Makarovic, 1977; Akima, 1978; Hutchinson and Bischof, 1983; Makarovic, 1984; Fortune, 1987; Hutchinson, 1989; Watson, 1992; Mitas and Mitasova, 1999). But there seems to be no single interpolation method that is the most accurate or universal for all kinds of data sources, terrain patterns, or purposes for the interpolation of terrain data (Fisher and Tate, 2006; Liu, 2008; Yurtseven *et al.*, 2019). However Bater and Coops (2009) showed that with using of the linear, natural neighbor, quintic, spline with tension, and ANUDEM (Australian National University DEM) interpolation techniques have better representations of the terrain and more accurate parameterizations than some of the other interpolation approaches.

Generally, in large-area forestry studies, standard topomap contour lines -based DEMs or the space-borne SRTM (Shuttle Radar Topography Mission), ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) GDEM (Global Digital Elevation Model) data are used to obtain the topographic metrics (Aydın and Tecimen, 2010; Jing *et al.*, 2014; Wong *et al.*, 2014; De Meij *et al.*, 2015; Mo *et al.*, 2015; Rather *et al.*, 2018).

With the increase in DEM data from various sources, users need to select the most appropriate DEM for a given application. In addition, during data processing, users are required to perform analyzes taking into account the data characteristics. Therefore, the aim of this study is to evaluate the effects of different data sources, different resolutions and different interpolation parameters on DEM derived metrics for large-area forestry applications. In this context, the two low-resolution DEM data sources (contour line based DEMs and ASTER GDEM) which are frequently used in forestry studies were compared with a state of art high-resolution LiDAR –based DEM data and the differences on some topographic metrics were evaluated. Initially, for these data sets, the pixel-based differences and the areal and volumetric differences between surface models were calculated. Thus, the differences between LiDAR –based DEM dataset, which is accepted as reference, and other DEM datasets were determined.

Slope and aspect are two of the most important topographic metrics affecting natural processes, applications and costs in forestry (Aruga *et al.*, 2007; Gonga-Saholiariliva *et al.*, 2011; Fernández-Landa *et al.*, 2018; Lidberg *et al.*, 2019). In this context, the area of the slope and aspect classes and the areal differences from the reference dataset were calculated for each data set. All results are discussed in terms of forestry, topography and data accuracy, and it is aimed to give researchers, operators and decision makers an idea in the selection of the optimal data to be used in their studies.

Material and methods

Study area

The research area is covered the northern part of Istanbul University's Education Research and Practice Forest close to Sariyer, Istanbul. The research field is at Thracian side of the Marmara Region between 28° 59' 17" – 29° 32' 25" east longitudes and 41° 09' 15" – 41° 11' 01" north latitudes according to Greenwich (Figure 1). The study area dimension is approximately 2724.16 m wide and 4006.86 m long, which covers an area of 1091.53 ha. According to the LiDAR based DEM data, the elevations range from 7.55 m up to over 237.17 m above sea level.

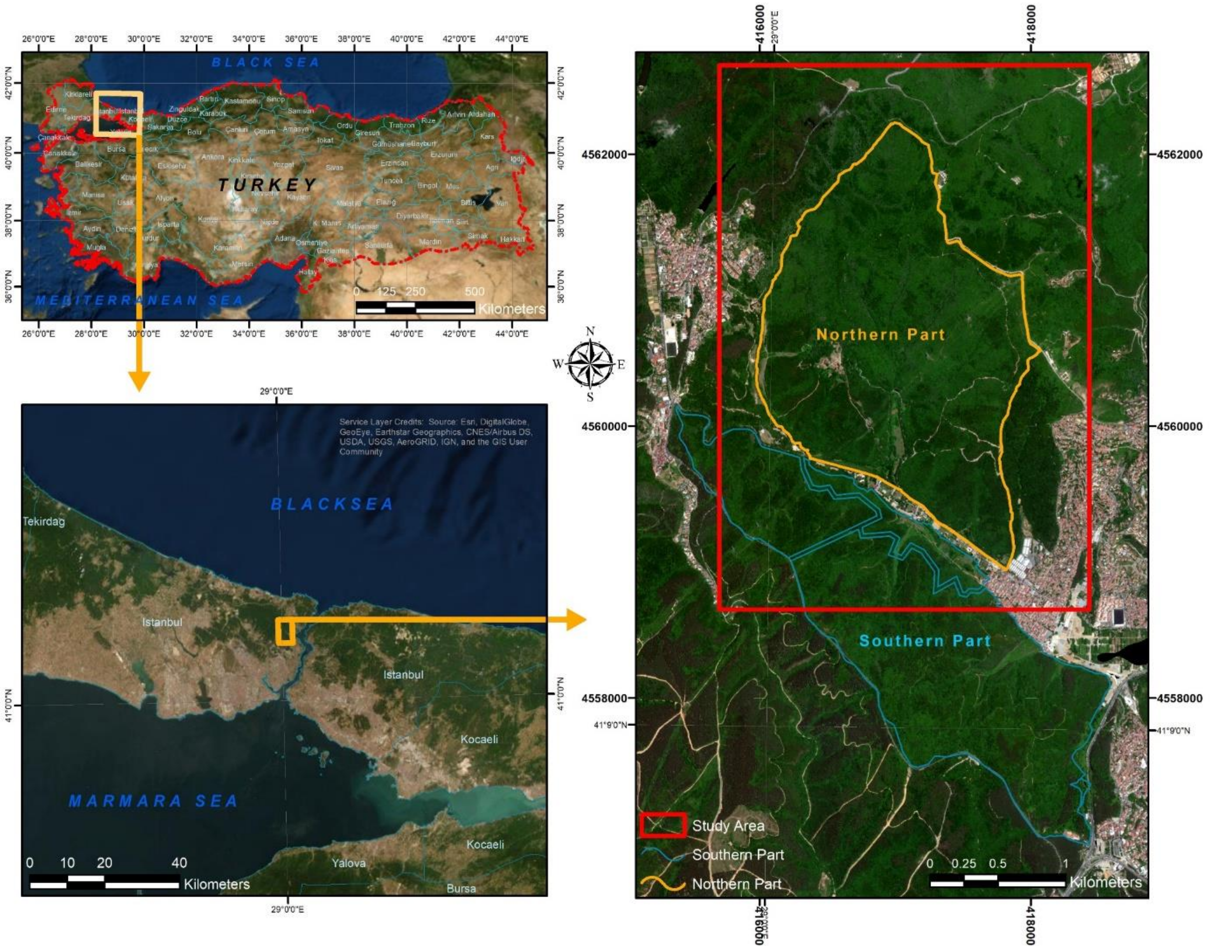


Figure 1. Study area.

DEM generation

In this study, topomap contour lines (-based DEMs), ASTER GDEM and LiDAR-based DEM data were employed (Figure 2). ASTER is one of five sensors and the only high spatial resolution instrument on the NASA's (National Aeronautics and Space Administration) Terra platform. ASTER is a result of the collaboration between NASA, Japan's Ministry of Economy, Trade and Industry (METI), and Japan Space Systems. As a result of this cooperation, ASTER products are freely available pursuant to an agreement between METI and NASA. ASTER GDEM version 2 (GDEM V2) product is generated using in-track stereo (nadir-viewing and backward-viewing) near infrared (VNIR) sensor imagery. ASTER GDEM V2 is organized according to a regular grid of 1 arc second (approximately 30 meters at the equator) and referenced to the 1984 World Geodetic System (WGS84)/1996 Earth Gravitational Model (EGM96) geoid (Tachikawa *et al.*, 2011).

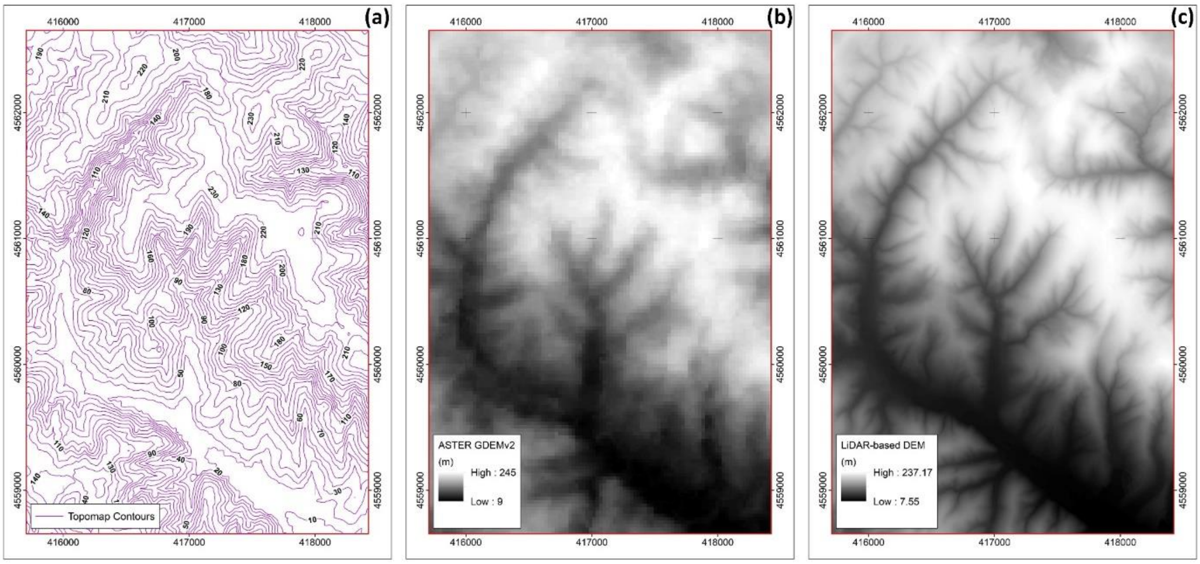


Figure 2. Topomap contour lines (a), ASTER GDEMv2 (b) and LiDAR-based DEM (c) data.

LiDAR-based DEM data were generated by the Greater Municipality of Istanbul with 0.25 m resolution. The point density of the raw point cloud data obtained by the Riegl Q680i laser scanner is approximately 16 points/m². The production of bare-earth DEM from the LiDAR point cloud involves two main steps: ground filtering and processing of filtered ground points in an interpolation routine (Aryal *et al.*, 2017). In the separating the ground and non-ground points, TIN, slope, interpolation, segmentation, morphological or interpretation –based approaches are widely used (Dragos and Karstenb, 2008; Polat and Uysal, 2015; Dong and Chen, 2017).

In the contour lines -based DEM production, contour lines (10 m interval) of 1:25000 scale aerial photogrammetry based standard topographical maps were used which are produced by National General Directorate of Mapping (General Directorate of Mapping, 2019). 1/25000 scale topomaps are frequently used in the forestry activities in Turkey. In this study, grid based DEMs are generated from contour lines by using TIN and ANUDEM based approaches.

The TIN method is frequently used in the production of DEM from contour lines. The TIN model represents a topographic surface with non-overlapping triangular polygons (Robinson *et al.*, 2009). Therefore, triangular-based surface modeling is a viable approach in any data model, such as regular grid sampling or contouring. However, grid-based models have many advantages in terms of data processing (Li *et al.*, 2005). In this context, the TIN model was transformed into grid-based models using linear (Lin) and natural neighbor (NN) interpolation processes.

Also in this study, the ANUDEM algorithm was used for DEM production due to its superiority. This algorithm removes spurious depressions in the fitted DEM, in recognition of the fact that sinks are usually quite rare in nature (Band, 1986; Goodchild and Mark, 1987). This method is iterative, employing a finite difference interpolation algorithm can use both point, line and polygon data to generate DEMs with realistic drainage characteristics. Compared to other interpolation routines significantly improve the drainage quality and overall structure of the fitted DEM, especially in data sparse areas. The procedure couples a drainage enforcement algorithm with a finite difference interpolation technique (Hutchinson, 1989, 1996; Wilson and Gallant, 2000; Bater and Coops, 2009). When the drainage enforcement is on, the algorithm attempts to remove all sinks it encounters. Enforce with sink option requires some user-defined tolerances or sink data entries. Any sink that is not defined in the input data is considered spurious and the algorithm tries to fill it. If the drainage enforcement option is off, no sink is filled (Hutchinson *et al.*, 2011).

The choice of the optimal grid resolution is an ongoing research topic and related to many different factors such as the point density, spatial accuracy of points, size of the area, processing power of the computer, geometry of the point patterns, complexity of the terrain, cartographic standards, and gridding or interpolation technique requirements (Hengl, 2006; Bater and Coops, 2009; Yurtseven, 2019). These factors can also affect slope and aspect mapping when determining DEM quality (Chang and Tsai, 1991).

In this context, grid resolution was determined by Nyquist frequency concept (Nyquist, 1924; Shannon, 1934). This concept is based on signal theory and indicates that the resolution of the grid should be at most half of the mean distance between the nearest point pairs ($\bar{d}_{mean}$) (Hengl, 2006).

$$Res. \leq \frac{\bar{d}_{mean}}{2} \tag{1}$$

Table 1. ANUDEM –based DEMs properties.

DEM dataset	**Resolution (m)**	**Drainage Enforcement**	**The Dominant Elevation Data Type**
Anudem_001	2.5	On	Contour
Anudem_002	2.5	On with Sink	Contour
Anudem_003	2.5	Off	Contour
Anudem_004	2.5	On	Point
Anudem_005	2.5	On with Sink	Point
Anudem_006	2.5	Off	Point
Anudem_007	5	On	Contour
Anudem_008	5	On with Sink	Contour
Anudem_009	5	Off	Contour
Anudem_010	5	On	Point
Anudem_011	5	On with Sink	Point
Anudem_012	5	Off	Point
Anudem_013	10	On	Contour
Anudem_014	10	On with Sink	Contour
Anudem_015	10	Off	Contour
Anudem_016	10	On	Point
Anudem_017	10	On with Sink	Point
Anudem_018	10	Off	Point
Anudem_019	30	On	Contour
Anudem_020	30	On with Sink	Contour
Anudem_021	30	Off	Contour
Anudem_022	30	On	Point
Anudem_023	30	On with Sink	Point
Anudem_024	30	Off	Point

When the contour line data used in the study were analyzed, it was found that the mean, minimum and maximum horizontal distances between the contour lines were 10.69 m, 4.92 m and 29.02 m, respectively. In this context, finest resolution was accepted as 2.5 m (half of the minimum horizontal distance). Also, 5 m (half of the mean horizontal distance) and 10 m resolutions were accepted in order to observe the effect of changes in resolution on the results of the analysis. In addition, the 30 m resolution offered by ASTER data was considered to be included in the study in order to compare the results. Thus, the use of four different resolutions was accepted in the production of interpolation-based DEM from contour lines data.

In this study, 32 interpolation –based DEM generated from topomap contour lines, with below mentioned parameters (Table 1, Table 2 and Figure 3). In total, 34 DEMs were used (including LiDAR based DEM) and 33 of them were analyzed.

Table 2. TIN to Raster –based DEMs properties.

DEM dataset	Resolution (m)	Interpolator
Tin_to_Raster_001	2.5	Linear
Tin_to_Raster_002	2.5	Natural Neighbor
Tin_to_Raster_003	5	Linear
Tin_to_Raster_004	5	Natural Neighbor
Tin_to_Raster_005	10	Linear
Tin_to_Raster_006	10	Natural Neighbor
Tin_to_Raster_007	30	Linear
Tin_to_Raster_008	30	Natural Neighbor

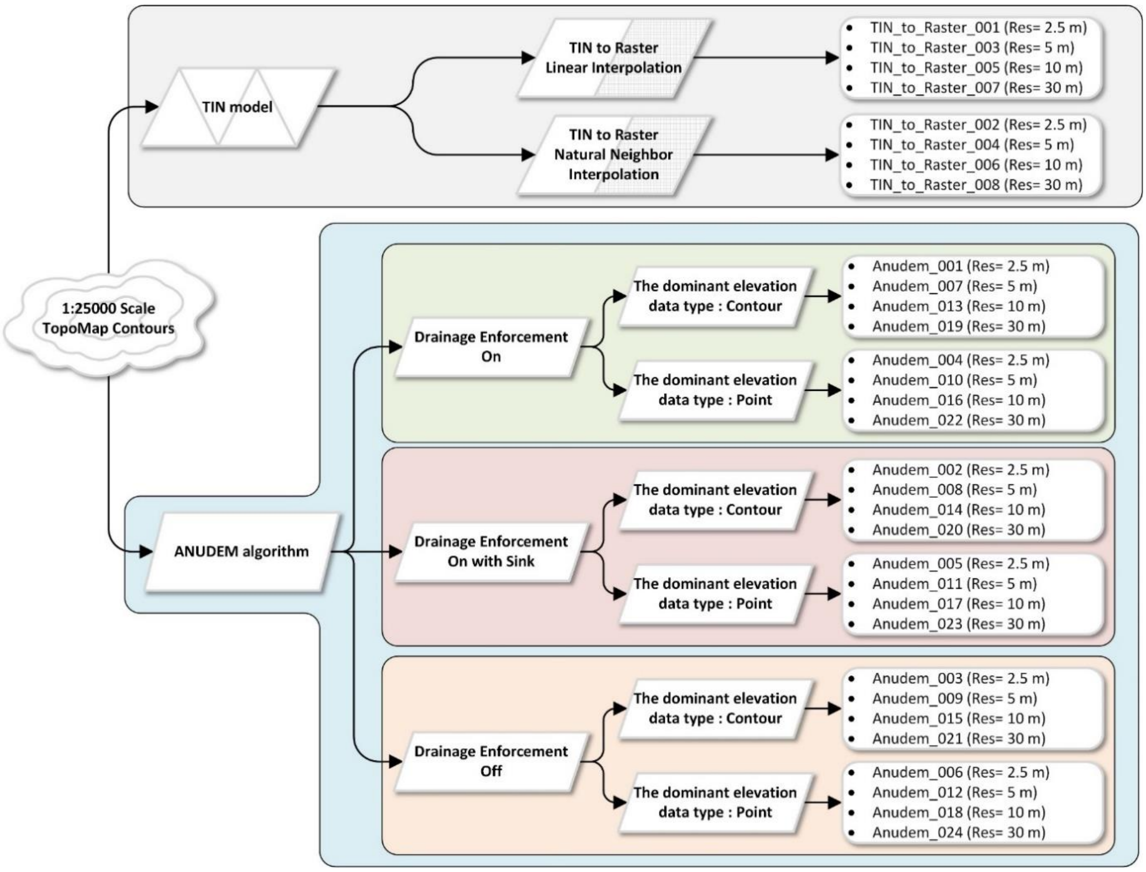


Figure 3. Contour –based DEM generation strategy.

Comparison Methodology

The coordinate system of the study is accepted as ED 1950 TM30 (EPSG: 2320). In order to perform a comparison horizontal and vertical coordinate transformations are performed for each datasets. After generating the surface models, data comparison procedures were performed. In this context, LiDAR based DEM and -derived datasets are accepted as reference.

In this stage, surface model, slope and aspect -based differences from the reference data were investigated. The surface –based evaluations were performed by calculating the pixel-based surface differences and evaluating the areal and volumetric differences of the DEMs. Pixel-based surface differences, ie, vertical residues, were calculated to determine the differences of each dataset from LiDAR –based DEM. In this context, descriptive statistics, mean differences, mean absolute differences and root mean square (RMS) differences were calculated and used as accuracy measures.

$$Mean\ Diff._{(Z)} = \frac{1}{n}\sum_{i=1}^{n}(\,Z_{Eva(i)} - Z_{Ref(i)}) \tag{2}$$

$$Mean\ Abs.Diff._{(Z)} = \frac{1}{n}\sum_{i=1}^{n}\left(\left|Z_{Eva(i)} - Z_{Ref(i)}\right|\right) \tag{3}$$

$$RMS\ Diff._{(Z)} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Z_{Eva(i)} - Z_{Ref(i)})^2} \tag{4}$$

To determine the areal and volumetric differences among the DEMs, the false positive, false negative, no difference, absolute difference zones and absolute difference volume per area were calculated for each datasets. In this context, the false positive defines the zones where the evaluated-reference difference is positive, and the false negative defines the zones where the evaluated-reference difference is negative (Figure 4) (Yurtseven, 2019).

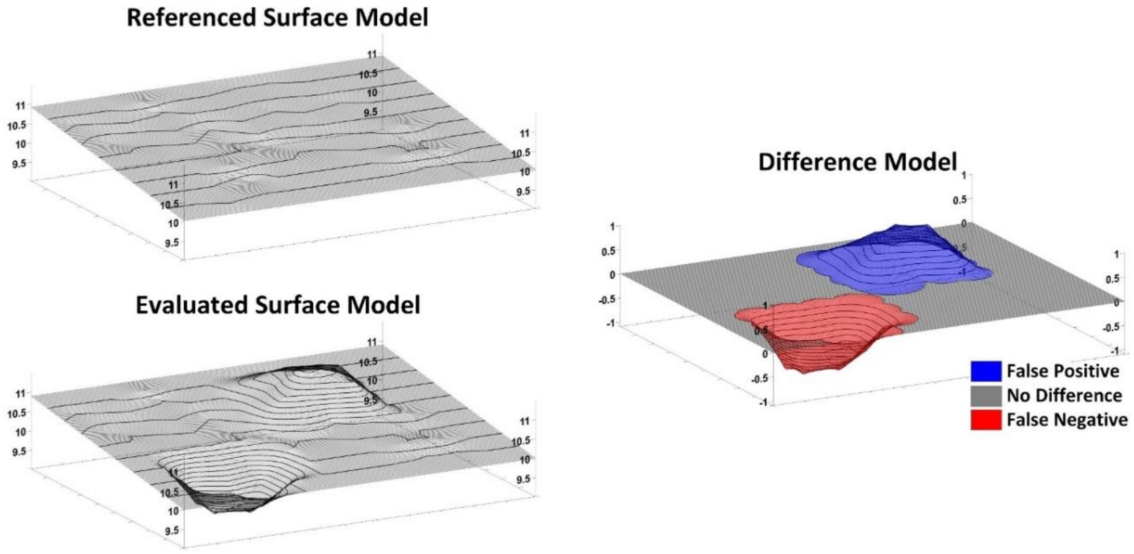


Figure 4. Visual definition of false positive, false negative and no difference areas and volumes.

The slope and aspect -based areal differences were evaluated on a class basis. The inclination of slope data was calculated as percent rise and slope data were analyzed in 11 classes (Table 3a). The aspect data were analyzed in 9 classes including 4 cardinal, 4 intercardinal directions and flat land (Table 3b).

Table 3. Slope (a) and aspect (b) classes.

Slope Classification	
Slope classes	**Slope gradient (%)**
1	< 5
2	5 – 10
3	10 – 15
4	15 – 20
5	20 – 30
6	30 – 40
7	40 – 50
8	50 – 60
9	60 – 80
10	80 – 100
11	100 <

Aspect Classification	
Aspect classes	**Aspect gradient (°)**
Flat	-1
North	0 – 22.5 , 337.5 – 360
Northeast	22.5 – 67.5
East	67.5 – 112.5
Southeast	112.5 – 157.5
South	157.5 – 202.5
Southwest	202.5 – 247.5
West	247.5 – 292.5
NorthWest	292.5 – 337.5

Results and Discussion

In the contour lines -based DEM production, TIN and ANUDEM –based approaches were used. By systematically differentiating the parameters of the two interpolation procedures, 32 DEMs were generated at four different resolutions from the contour line dataset. In total 33 DEMs, including ASTER GDEMv2 were analyzed (Appendix 1-DEM Datasets). For all interpolation algorithms and all spatial resolutions, global pixel-based difference statistics from LiDAR-based DEM are presented in Table 4 and Figure 5. Also difference DEMs are presented in Appendix 2-Difference DEMs. While the mean difference for all of the datasets except for the ASTER dataset were sub-meter, the difference range vary between 63.23 and 84.50 m, and the standard deviation of difference ranged from 4.72 to 9.53 m. Generally all the global difference metrics are increasing for all interpolation routines as spatial resolution increased from 30 to 2.5 m. At lower resolutions (10 and 30 m) ANUDEM-based DEMs showed better parameterization, while at higher resolutions (2.5 and 5 m) the situation was similar for the TIN to raster and ANUDEM –based approaches. All metric values were consistent for all interpolation routines up to 30 m resolution. For 30 m resolution, the mean differences submitted the lowest, the difference ranges and the standard deviations submitted the highest values.

TIN-derived DEMs contain directional surfaces at all resolutions. The ANUDEM algorithm generated surfaces which were smooth and represent the topography better (Figure 6). However, DEMs generated using both ANUDEM and TIN based interpolators particularly at higher resolutions, have topographic steps due to the use of contour line data as the base.

The mean and RMS differences of ASTER GDEM v2 from LiDAR –based DEM in our study region are 7.39 m and 11.10 m, respectively. According to Tachikawa *et al.* (2011), the planned mean errors for the GDEM v2 is -0.2 m.. Mukherjee *et al.* (2013), Rexer and Hirt (2014) and Szabó *et al.* (2015) reported that the vertical error of ASTER GDEM v2 is 2.7 m with 9.1 m RMSE, 2.58 m with 9.2 m RMSE and -4.2 m with 9.2 m RMSE, respectively.

It can be considered that there are some reasons for the occurrence of such a difference from previous studies. As is known, stereo-correlations are more difficult in forest areas due to the textural properties of vegetation-covered surfaces and their low color contrast. Therefore, fewer points meet threshold correlation criteria, and this kind of surfaces are represented by lower point densities and lower accuracy rates in the photogrammetric model.

Topomap contour lines and ASTER GDEM data used in the study were produced by using photogrammetric techniques. In this context, contour lines are generated by manual interpretation using stereoscopic models. In the stereoscopic model, aerial imagery are used. ASTER DEM data is generated by automated techniques using stereoscopic image matching algorithms on satellite imagery. Both methods have advantages and disadvantages. In this context, interpretation based errors, atmospheric effects (haze, lightning conditions), spatial accuracy of stereoscopic models, etc. can be attributed as error sources.

Table 4. Global difference statistics from LiDAR-based DEM.

DEM dataset	Res. (m)	Mean Diff. (m)	Min Diff. (m)	Max Diff. (m)	Diff. Range (m)	Std. Dev. of Diff. (m)	Mean Absolute Diff. (m)	RMS Diff. (m)
Anudem_001	2.5	0.71	-34.26	30.53	64.79	4.72	3.42	4.78
Anudem_002	2.5	0.71	-34.26	30.53	64.79	4.72	3.42	4.78
Anudem_003	2.5	0.72	-34.26	30.64	64.90	4.73	3.43	4.79
Anudem_004	2.5	0.54	-34.26	30.14	64.40	4.88	3.58	4.91
Anudem_005	2.5	0.65	-34.26	30.40	64.66	4.95	3.66	4.99
Anudem_006	2.5	0.65	-34.26	30.40	64.66	4.95	3.66	4.99
Tin_to_Raster_001	2.5	0.66	-34.07	30.29	64.36	5.04	3.75	5.08
Tin_to_Raster_002	2.5	0.64	-33.98	30.29	64.27	5.04	3.75	5.08
Anudem_007	5	0.67	-35.57	28.93	64.50	5.01	3.66	5.06
Anudem_008	5	0.67	-35.57	28.93	64.50	5.01	3.66	5.06
Anudem_009	5	0.67	-35.57	29.01	64.58	5.02	3.67	5.06
Anudem_010	5	0.51	-35.59	28.24	63.83	5.15	3.80	5.17
Anudem_011	5	0.61	-35.59	29.08	64.67	5.20	3.87	5.24
Anudem_012	5	0.61	-35.59	29.08	64.67	5.20	3.87	5.24
Tin_to_Raster_003	5	0.65	-34.97	30.48	65.46	5.15	3.84	5.19
Tin_to_Raster_004	5	0.63	-34.85	30.48	65.33	5.15	3.85	5.18
Anudem_013	10	0.55	-38.05	27.26	65.31	5.74	4.26	5.76
Anudem_014	10	0.55	-38.05	27.26	65.31	5.74	4.26	5.88
Anudem_015	10	0.55	-38.05	27.26	65.32	5.74	4.27	5.77
Anudem_016	10	0.42	-38.02	27.26	65.28	5.83	4.36	5.84
Anudem_017	10	0.50	-38.02	27.35	65.37	5.86	4.41	5.76
Anudem_018	10	0.50	-38.02	27.35	65.37	5.86	4.41	5.88
Tin_to_Raster_005	10	0.59	-36.63	27.80	64.43	5.37	4.03	5.40
Tin_to_Raster_006	10	0.57	-36.42	26.80	63.23	5.36	4.03	5.39
Anudem_019	30	0.09	-46.79	37.58	84.37	9.52	7.27	9.52
Anudem_020	30	0.09	-46.79	37.58	84.37	9.52	7.27	9.52
Anudem_021	30	0.08	-46.79	37.59	84.38	9.53	7.27	9.53
Anudem_022	30	0.06	-46.67	37.80	84.47	9.53	7.29	9.53
Anudem_023	30	0.08	-46.68	37.82	84.50	9.53	7.31	9.53
Anudem_024	30	0.08	-46.68	37.82	84.50	9.53	7.31	9.53
Tin_to_Raster_007	30	0.42	-39.15	30.27	69.42	6.77	5.12	6.78
Tin_to_Raster_008	30	0.40	-39.15	30.27	69.42	6.76	5.12	6.77
Aster	30	7.39	-28.46	48.19	76.65	8.29	8.91	11.10

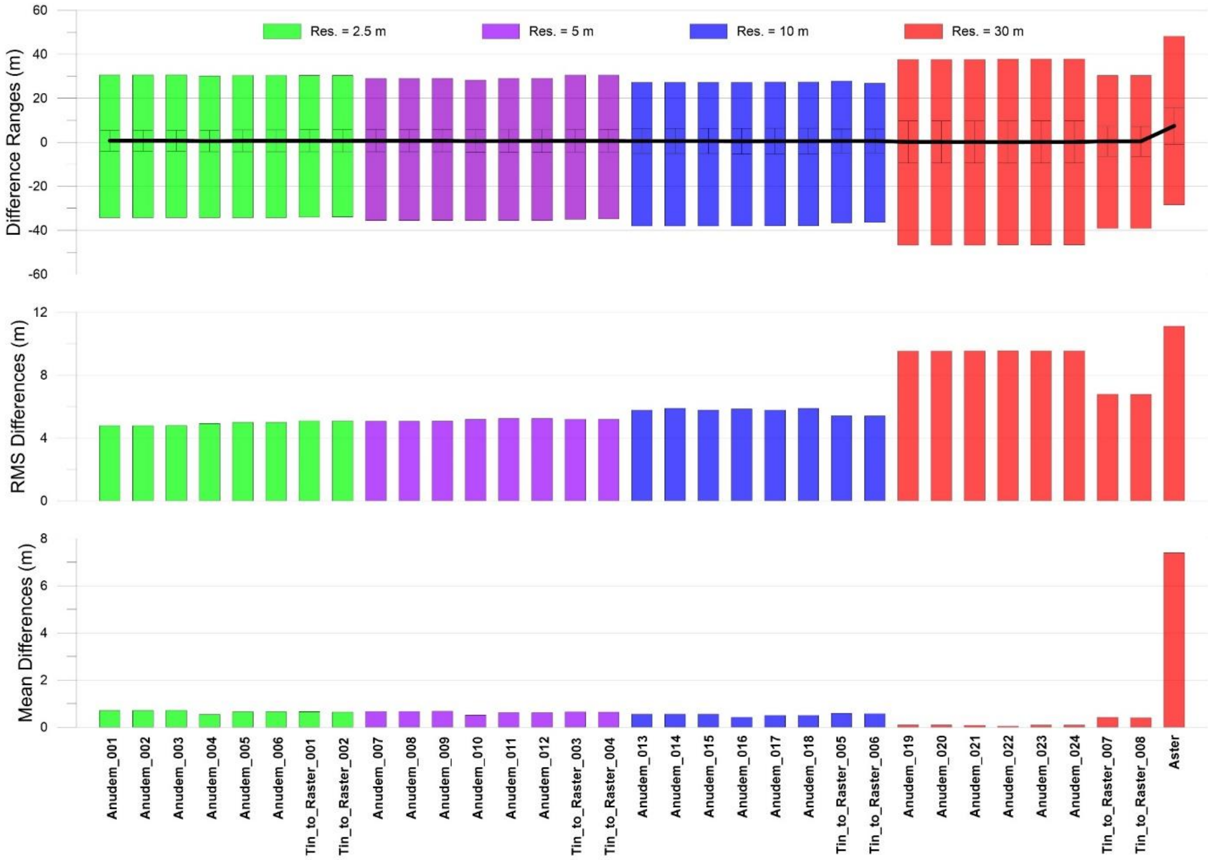


Figure 5. Global difference statistics.

Also, the purpose of manual interpretation is to produce topographic information about the bare soil surface; ASTER GDEM data presents a model with topography of man-made objects (such as structure) and vegetation. The study area is mostly covered with forest. In this context, the mean positive difference value of 7.39 m presented by ASTER data is significant because the reference data set has bare-earth topographic information. However, this can only be an explanation for positive values. Since LiDAR data is generated using laser-based detection techniques, the data generated from both data sources is never reached the details provided by the LiDAR data. Therefore, local topographic variability can be modeled more accurately with LiDAR data. In this context, negative values were attributed to the inability of both datasets to reach the high detail and resolution presented by the LiDAR data.

The areal and volumetric difference analyses were performed for the ANUDEM, TIN and ASTER -based DEMs. In this context, the false positive (F.P.), false negative (F.N) and the no difference zones from LiDAR-based DEM were determined for each datasets (Appendix 3-DEM Difference Zones). The total (T. Diff.) and absolute total (A.T. Diff.) areal and volumetric differences were also calculated (Table 5 and Figure 7).

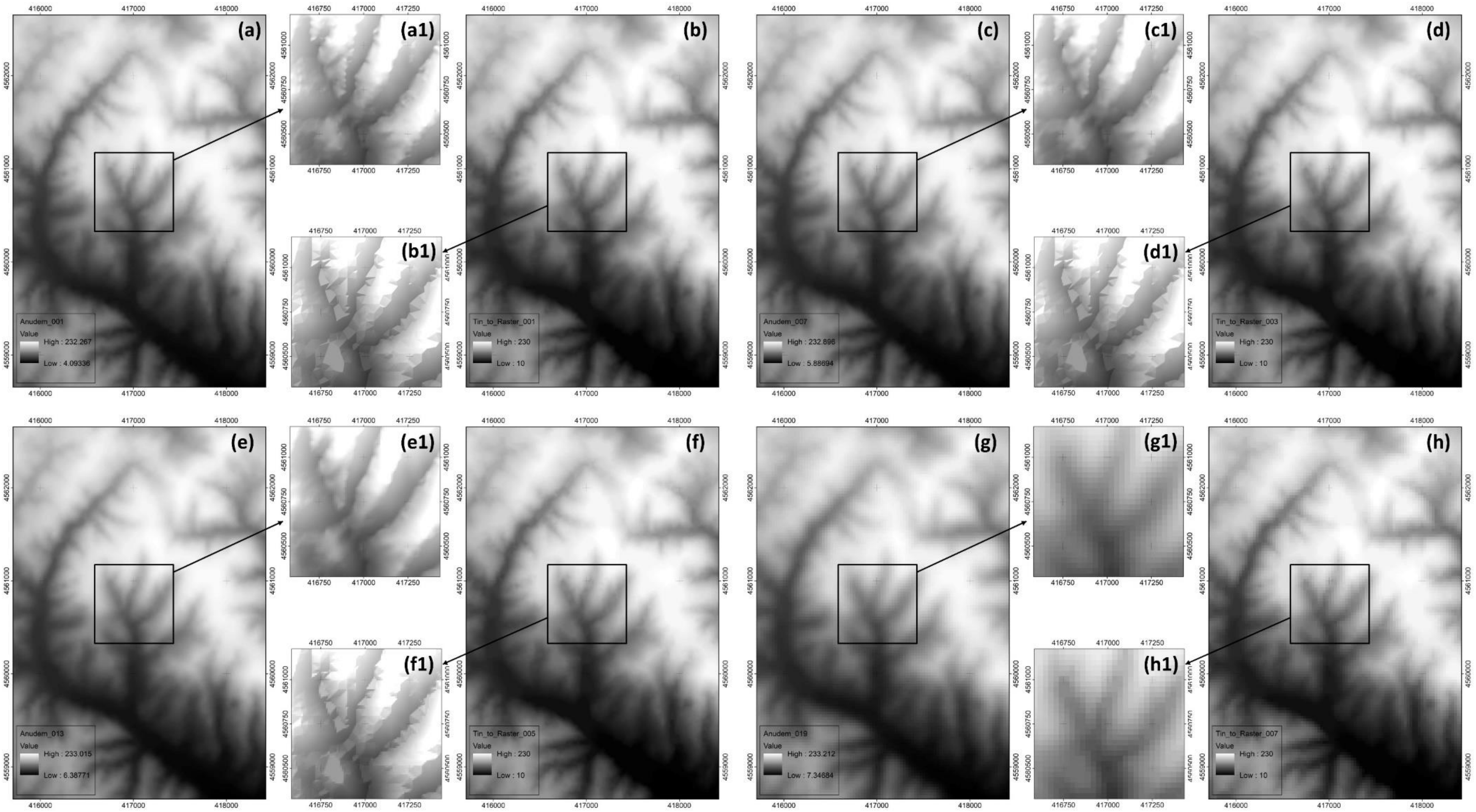


Figure 6. 1:25000 scale contour line –based DEM visuals. Resolution = 2.5 m; Anudem_001 (a, a1), Tin_to_Raster_001 (b, b1). Resolution = 5 m; Anudem_007 (c, c1), Tin_to_Raster_003 (d, d1). Resolution = 10 m; Anudem_013 (e, e1), Tin_to_Raster_005 (f, f1). Resolution = 30 m; Anudem_019 (g, g1), Tin_to_Raster_007 (h, h1).

Table 5. Volumetric and areal differences from LiDAR-based DEM.

DEM dataset	**Resolution (m)**	**Area (ha)**					**Volume ($m^3 \times 10^6$)**				**Absolute Difference per Area (m^3/ha)**
		False Negative	**False Positive**	**No Difference**	**Total Difference**	**Absolute Total Difference**	**False Negative**	**False Positive**	**Total Difference**	**Absolute Total Difference**	
Anudem_001	2.5	506.25	583.48	0.00	77.23	1089.73	14.220	22.182	7.962	36.401	33403.97
Anudem_002	2.5	506.25	583.48	0.00	77.23	1089.73	14.220	22.182	7.962	36.401	33403.97
Anudem_003	2.5	505.46	584.27	0.00	78.80	1089.73	14.238	22.278	8.041	36.516	33509.34
Anudem_004	2.5	523.58	566.15	0.00	42.56	1089.73	16.019	22.107	6.089	38.126	34986.48
Anudem_005	2.5	510.42	579.31	0.00	68.89	1089.73	15.872	23.225	7.352	39.097	35877.68
Anudem_006	2.5	510.42	579.31	0.00	68.89	1089.73	15.872	23.225	7.352	39.097	35877.68
Tin_to_Raster_001	2.5	508.43	581.14	0.16	72.71	1089.57	16.456	23.851	7.395	40.308	36994.32
Tin_to_Raster_002	2.5	511.22	578.39	0.13	67.17	1089.60	16.573	23.795	7.222	40.368	37048.00
Anudem_007	5	508.78	580.95	0.00	72.17	1089.73	14.679	22.276	7.597	36.954	33911.58
Anudem_008	5	508.78	580.95	0.00	72.17	1089.73	14.679	22.276	7.597	36.954	33911.58
Anudem_009	5	508.50	581.22	0.01	72.72	1089.73	14.695	22.348	7.653	37.043	33992.59
Anudem_010	5	523.01	566.72	0.00	43.71	1089.73	16.341	22.235	5.895	38.576	35399.23
Anudem_011	5	511.67	578.05	0.00	66.38	1089.73	16.218	23.218	7.000	39.436	36188.74
Anudem_012	5	511.67	578.05	0.00	66.38	1089.73	16.218	23.218	7.000	39.436	36188.74
Tin_to_Raster_003	5	508.23	581.35	0.16	73.12	1089.57	16.449	23.840	7.392	40.289	36976.82
Tin_to_Raster_004	5	511.03	578.57	0.14	67.55	1089.60	16.565	23.784	7.219	40.349	37030.81
Anudem_013	10	512.57	577.17	0.00	64.60	1089.73	15.946	22.954	7.008	38.900	35697.14
Anudem_014	10	512.57	577.17	0.00	64.60	1089.73	15.946	22.954	7.008	38.900	35697.14
Anudem_015	10	513.24	576.50	0.00	63.26	1089.73	15.986	22.999	7.012	38.985	35775.12
Anudem_016	10	523.35	566.39	0.00	43.04	1089.73	17.350	22.937	5.587	40.288	36970.31
Anudem_017	10	515.85	573.89	0.00	58.04	1089.73	17.274	23.715	6.441	40.989	37613.69
Anudem_018	10	515.85	573.89	0.00	58.04	1089.73	17.274	23.715	6.441	40.989	37613.69
Tin_to_Raster_005	10	508.42	581.17	0.14	72.75	1089.59	16.419	23.848	7.430	40.267	36956.05
Tin_to_Raster_006	10	511.54	578.07	0.12	66.53	1089.61	16.531	23.789	7.257	40.320	37004.11
Anudem_019	30	532.36	557.38	0.00	25.02	1089.73	26.059	29.753	3.694	55.812	51216.19
Anudem_020	30	532.36	557.38	0.00	25.02	1089.73	26.059	29.753	3.694	55.812	51216.19
Anudem_021	30	534.16	555.58	0.00	21.42	1089.73	26.164	29.723	3.559	55.886	51284.71
Anudem_022	30	537.31	552.43	0.00	15.12	1089.73	26.638	29.947	3.309	56.585	51925.55
Anudem_023	30	532.36	557.38	0.00	25.02	1089.73	26.656	30.286	3.630	56.942	52253.41
Anudem_024	30	532.36	557.38	0.00	25.02	1089.73	26.656	30.286	3.630	56.942	52253.41
Tin_to_Raster_007	30	509.41	580.15	0.18	70.74	1089.55	16.579	23.871	7.291	40.450	37125.35
Tin_to_Raster_008	30	513.73	575.83	0.18	62.10	1089.55	16.674	23.795	7.121	40.469	37143.22
Aster	30	153.26	936.25	0.22	782.98	1089.51	6.162	89.569	83.407	95.731	87866.40

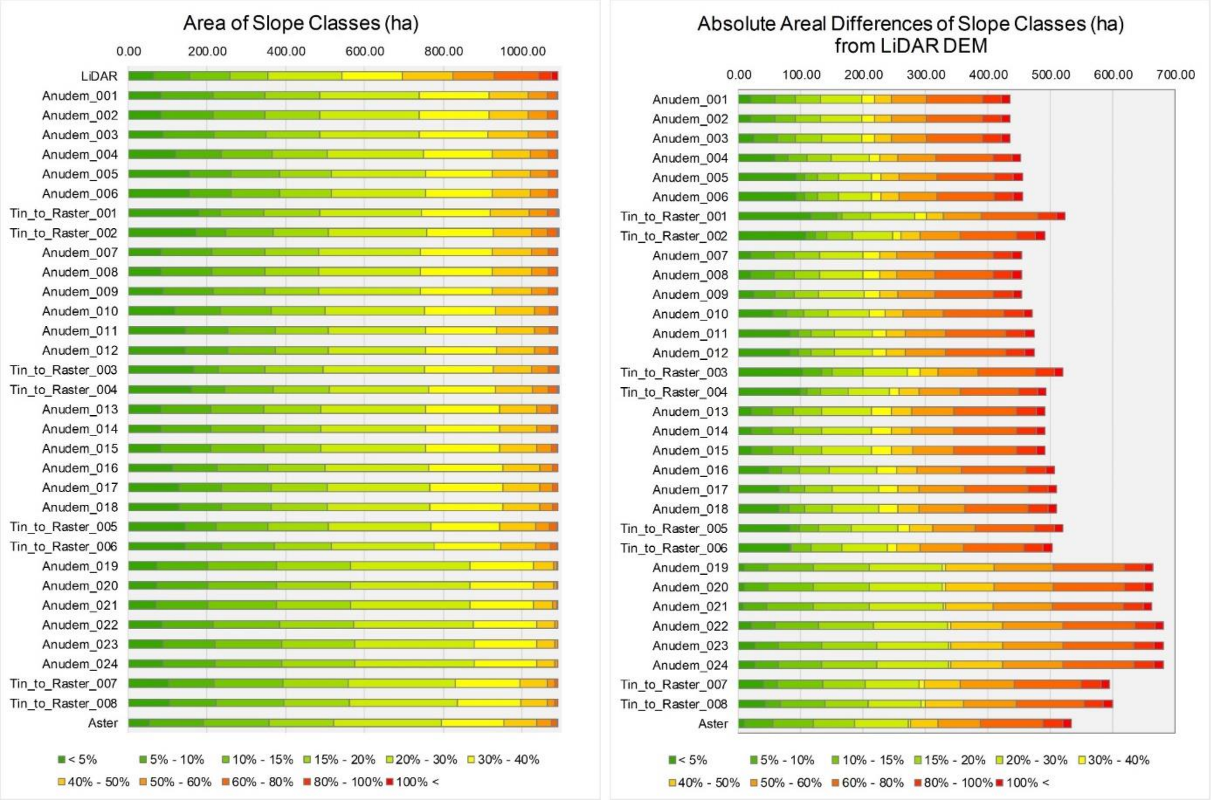
The areal and volumetric difference analysis results indicated that TIN to Raster –based DEMs delivered the most consistent results at all resolutions. ASTER GDEMv2 has the worst results as can be predicted from the difference statistics. When the analysis results were interpreted, it was found that the false positive values were slightly higher than the false negative values for areal differences. On the other hand, the situation in volumetric differences is considerable. The false positive values for volumetric differences were approximately 7 $m^3 \times 10^6$ higher than the false negative values, up to 30 m resolution both for ANUDEM and TIN –based approaches. ANUDEM-based DEMs delivered significant results up to 10 m resolution, whereas the difference values have increased as the resolution decreased to 30 m.

Figure 7. Areal and volumetric differences

According to the LiDAR –based DEM –derived slope data, there was a wide range of slope differences in the study area (Appendix 4-Slope Datasets, Appendix 5-Slope Dataset Statistics) and for all slope classes areal distributions were variable (Figure 8, Appendix 6-Area of Slope Classes). According to the slope statistics, the mean and the standard deviation of slope is decreased with increasing the resolution, as similarly reported by Evans (1980), Zhang *et al.* (1999) and Chen and Zhou (2013). When the slope difference analysis results were interpreted, it was found that the difference values up to 40-50 % slope were positive and for slope classes greater than 40-50 % were negative (Table 6). In addition, it was another considerable point that areal slope difference values tended to decrease with increasing resolution of interpolation-based DEMs (Table 6 and Figure 8). The best comparison results were obtained by "Anudem_003" dataset at all resolutions. Respectively, Anudem_009 at 5m resolution, Anudem_013-014 at 10m resolution, and ASTER datasets at 30m resolution had the best results.

Table 6. Areal differences of Slope classes from LiDAR-based DEM.

Slope dataset	**Areal Differences of Slope (%) Classes from LiDAR-based DEM (ha)**											**Std. Dev. of Diff.**	**Abs. Total Diff.**
	< 5	5–10	10–15	15–20	20–30	30–40	40–50	50–60	60–80	80–100	100 <		
Anudem_001	20.21	38.41	31.64	42.00	65.28	20.18	-26.79	-57.35	-89.32	-30.09	-14.19	45.13	435.45
Anudem_002	20.21	38.41	31.64	42.00	65.28	20.18	-26.79	-57.35	-89.32	-30.09	-14.19	45.13	435.45
Anudem_003	25.33	36.54	29.43	41.14	65.37	19.82	-26.82	-57.23	-89.28	-30.10	-14.19	45.00	435.24
Anudem_004	58.53	20.76	30.34	39.69	59.46	17.25	-28.74	-60.87	-91.55	-30.69	-14.19	46.94	452.06
Anudem_005	92.67	12.84	20.57	34.45	52.96	13.89	-30.01	-60.97	-91.56	-30.65	-14.19	50.00	454.76
Anudem_006	92.67	12.84	20.57	34.45	52.96	13.89	-30.01	-60.97	-91.56	-30.65	-14.19	50.00	454.76
Tin_to_Raster_001	116.66	-39.94	9.05	46.25	70.15	19.56	-26.93	-60.69	-89.94	-30.08	-14.09	57.47	523.34
Tin_to_Raster_002	107.97	-15.29	18.20	41.08	63.95	13.99	-31.00	-63.33	-91.19	-30.28	-14.09	54.44	490.38
Anudem_007	19.70	37.76	31.44	40.10	70.97	26.64	-27.63	-60.65	-93.28	-30.87	-14.19	47.15	453.24
Anudem_008	19.70	37.76	31.44	40.10	70.97	26.64	-27.63	-60.65	-93.28	-30.87	-14.19	47.15	453.24
Anudem_009	24.15	35.10	29.80	39.87	71.38	26.57	-27.82	-60.63	-93.34	-30.90	-14.19	47.11	453.75
Anudem_010	55.68	21.40	27.49	39.64	65.93	25.15	-29.21	-64.46	-95.91	-31.50	-14.19	48.86	470.55
Anudem_011	82.86	13.47	20.57	36.15	61.32	22.28	-30.26	-64.81	-95.91	-31.48	-14.19	50.94	473.29
Anudem_012	82.86	13.47	20.57	36.15	61.32	22.28	-30.26	-64.81	-95.91	-31.48	-14.19	50.94	473.29
Tin_to_Raster_003	103.43	-30.25	17.17	49.13	71.18	19.29	-29.72	-63.29	-92.20	-30.58	-14.16	55.83	520.41
Tin_to_Raster_004	98.61	-10.46	22.74	44.08	66.11	14.77	-32.89	-65.16	-92.98	-30.68	-14.16	53.93	492.65
Anudem_013	20.68	33.06	33.98	45.87	78.98	32.95	-32.27	-67.44	-99.95	-31.66	-14.19	51.25	491.03
Anudem_014	20.68	33.06	33.98	45.87	78.98	32.95	-32.27	-67.44	-99.95	-31.66	-14.19	51.25	491.03
Anudem_015	21.41	31.94	34.52	46.18	79.06	32.78	-32.72	-67.32	-100.02	-31.63	-14.19	51.29	491.77
Anudem_016	49.09	20.53	28.66	46.21	76.52	32.15	-32.94	-71.67	-102.47	-31.88	-14.19	52.76	506.31
Anudem_017	65.94	15.11	25.38	44.16	74.39	30.01	-34.91	-71.60	-102.40	-31.88	-14.19	53.64	509.97
Anudem_018	65.94	15.11	25.38	44.16	74.39	30.01	-34.91	-71.60	-102.40	-31.88	-14.19	53.64	509.97
Tin_to_Raster_005	82.88	-14.48	29.95	54.10	74.49	18.57	-36.35	-67.81	-95.96	-31.20	-14.19	54.85	519.98
Tin_to_Raster_006	82.64	-2.09	31.97	49.52	71.61	15.51	-38.26	-68.91	-96.48	-31.32	-14.19	54.26	502.50
Anudem_019	9.00	37.92	72.00	90.84	117.55	4.65	-77.76	-94.31	-113.83	-31.88	-14.19	72.56	663.94
Anudem_020	9.00	37.92	72.00	90.84	117.55	4.65	-77.76	-94.31	-113.83	-31.88	-14.19	72.56	663.94
Anudem_021	7.56	38.01	74.25	90.48	117.28	3.66	-77.40	-93.86	-113.92	-31.88	-14.19	72.59	662.50
Anudem_022	21.60	37.83	69.03	88.23	118.54	5.19	-81.90	-98.00	-114.46	-31.88	-14.19	73.33	680.86
Anudem_023	26.37	36.93	69.30	88.32	115.39	3.75	-82.53	-97.01	-114.46	-31.88	-14.19	72.95	680.14
Anudem_024	26.37	36.93	69.30	88.32	115.39	3.75	-82.53	-97.01	-114.46	-31.88	-14.19	72.95	680.14
Tin_to_Raster_007	39.33	22.53	72.54	69.15	85.78	7.98	-58.23	-85.85	-107.17	-31.88	-14.19	62.51	594.64
Tin_to_Raster_008	42.84	23.88	71.46	68.97	85.60	6.81	-60.66	-85.40	-107.44	-31.88	-14.19	62.80	599.14
Aster	-9.68	45.29	64.16	67.18	86.30	3.65	-44.07	-67.56	-100.16	-30.92	-14.19	57.15	533.16


Area of Slope Classes (ha)

Absolute Areal Differences of Slope Classes (ha) from LiDAR DEM

Figure 8. Area of slope classes and absolute areal differences of slope classes from LiDAR DEM.

According to the LiDAR –based DEM –derived aspect data, there was no dominant aspect class in the study area (Appendix 7-Aspect Datasets, Appendix 8-Area of Aspect Classes). However, when the results were examined closely, maximum areal differences were obtained in the northwest aspect classes (Table 7, Figure 9). According to the results of the areal differences of aspect classes the best results were obtained by the "Anudem_003" dataset. Similar to the slope difference results, Anudem_009 at 5 m resolution, Anudem_013-014 at 10m resolution and ASTER at 30m resolution had the best comparison results.

Table 7. Areal differences of aspect classes from LiDAR-based DEM.

Aspect Dataset	**Areal Differences of Aspect Classes from LiDAR-based DEM (ha)**									**Std. Dev. of Diff.**	**Abs. Total Diff.**
	Flat	North	NorthEast	East	SouthEast	South	SouthWest	West	NorthWest		
Anudem_001	-7.10	11.64	-5.13	-3.96	-2.05	18.19	17.39	-1.35	-27.62	13.46	94.43
Anudem_002	-7.10	11.64	-5.13	-3.96	-2.05	18.19	17.39	-1.35	-27.62	13.46	94.43
Anudem_003	-7.10	11.77	-5.59	-4.25	-1.07	17.37	17.26	-1.52	-26.87	13.18	92.78
Anudem_004	-7.10	8.11	-0.19	-9.14	0.56	19.29	19.69	-3.47	-27.76	13.92	95.32
Anudem_005	-7.10	8.57	-3.84	-8.08	3.19	20.97	20.77	-6.86	-27.62	14.51	107.00
Anudem_006	-7.10	8.57	-3.84	-8.08	3.19	20.97	20.77	-6.86	-27.62	14.51	107.00
Tin_to_Raster_001	153.77	-9.15	-20.20	-26.85	-18.86	-9.23	-0.06	-34.31	-35.12	55.49	307.55
Tin_to_Raster_002	105.65	-5.77	-16.09	-23.96	-8.41	1.19	8.77	-28.32	-33.05	39.54	231.20
Anudem_007	-7.10	11.61	-4.64	-4.70	-1.20	17.61	18.68	-0.87	-29.40	13.96	95.82
Anudem_008	-7.10	11.61	-4.64	-4.70	-1.20	17.61	18.68	-0.87	-29.40	13.96	95.82
Anudem_009	-7.10	11.87	-5.20	-5.12	0.18	16.35	18.56	-0.85	-28.68	13.66	93.89
Anudem_010	-7.10	8.82	-1.93	-7.23	1.81	19.91	18.63	-4.12	-28.79	14.05	98.34
Anudem_011	-7.10	8.91	-4.50	-7.02	3.99	20.23	20.36	-6.24	-28.62	14.52	106.96
Anudem_012	-7.10	8.91	-4.50	-7.02	3.99	20.23	20.36	-6.24	-28.62	14.52	106.96
Tin_to_Raster_003	127.84	-7.28	-17.23	-25.02	-12.65	-6.94	5.44	-31.32	-32.85	46.69	266.58
Tin_to_Raster_004	87.34	-4.50	-13.93	-22.46	-4.05	2.57	12.43	-26.40	-31.01	33.64	204.69

Anudem_013	-7.10	12.67	-4.64	-5.77	0.42	20.64	15.22	-0.26	-31.19	14.52	97.93
Anudem_014	-7.10	12.67	-4.64	-5.77	0.42	20.64	15.22	-0.26	-31.19	14.52	97.93
Anudem_015	-7.10	13.09	-4.75	-6.07	1.17	19.00	16.29	-0.84	-30.80	14.37	99.13
Anudem_016	-7.10	10.30	-2.95	-7.45	2.46	21.28	16.67	-2.36	-30.86	14.59	101.45
Anudem_017	-7.10	11.10	-5.48	-6.94	4.38	21.30	16.87	-3.76	-30.38	14.71	107.33
Anudem_018	-7.10	11.10	-5.48	-6.94	4.38	21.30	16.87	-3.76	-30.38	14.71	107.33
Tin_to_Raster_005	90.75	-4.38	-12.95	-22.23	-4.61	-3.27	13.14	-27.00	-29.45	34.51	207.78
Tin_to_Raster_006	62.24	-2.23	-10.64	-20.33	0.88	5.10	16.15	-22.47	-28.70	25.87	168.74
Anudem_019	-7.10	6.71	5.03	-12.90	8.88	21.05	25.94	-9.02	-38.59	18.42	135.22
Anudem_020	-7.10	6.71	5.03	-12.90	8.88	21.05	25.94	-9.02	-38.59	18.42	135.22
Anudem_021	-7.10	6.71	5.30	-12.90	8.43	20.69	25.76	-8.39	-38.50	18.27	133.78
Anudem_022	-7.10	6.08	5.03	-12.36	6.54	24.02	21.80	-5.78	-38.23	17.81	126.94
Anudem_023	-7.10	6.35	4.85	-11.91	7.35	23.93	21.08	-6.23	-38.32	17.75	127.12
Anudem_024	-7.10	6.35	4.85	-11.91	7.35	23.93	21.08	-6.23	-38.32	17.75	127.12
Tin_to_Raster_007	25.84	0.59	-1.00	-22.08	13.56	4.94	23.78	-16.67	-28.96	18.40	137.43
Tin_to_Raster_008	16.39	1.58	-1.09	-20.91	15.27	8.90	22.07	-12.98	-29.23	16.77	128.43
Aster	-6.73	10.33	4.18	-5.09	-5.37	26.02	13.44	-14.48	-22.30	14.10	107.93

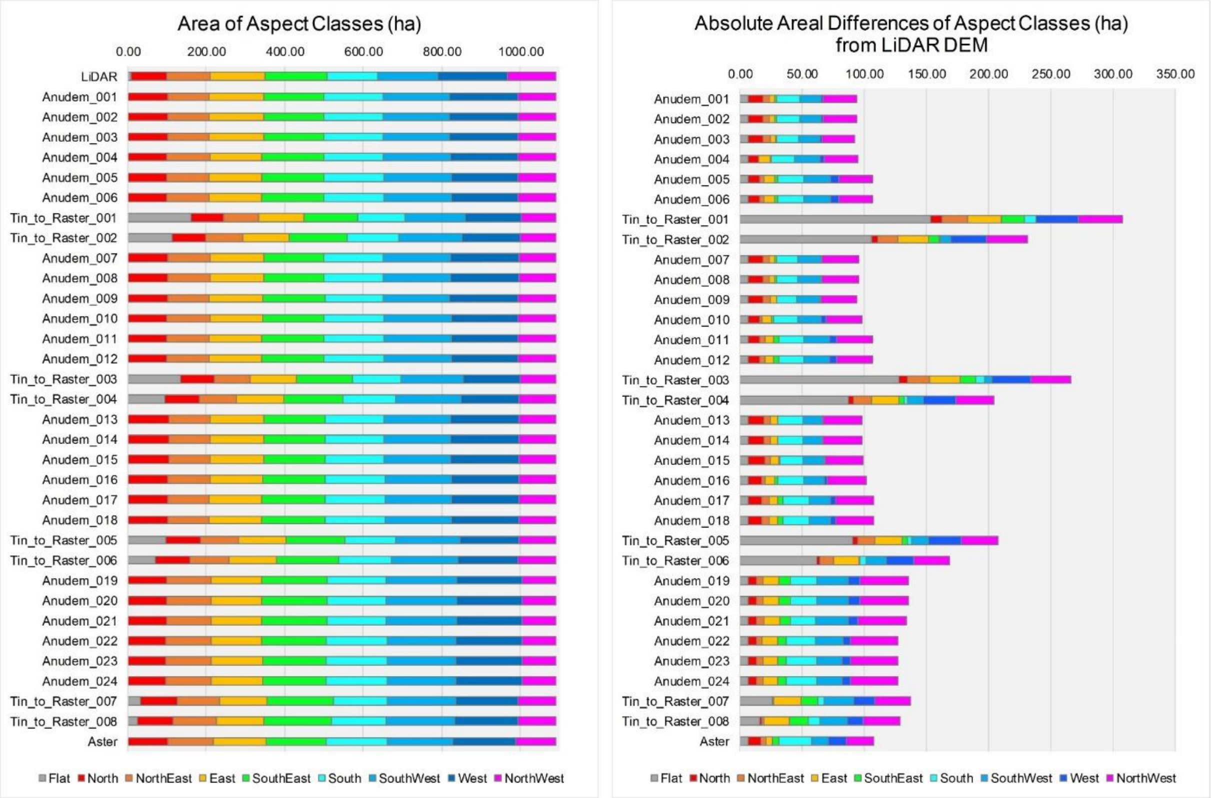


Figure 9. Area of aspect classes and absolute areal differences of aspect classes from LiDAR DEM.

According to slope and aspect differences analysis results, percentage differences were presented in Appendix 9-Absolute % Difference for each Slope Class and Appendix 10-Absolute % Difference for each Aspect Class for each slope and aspect classes. For all slope datasets, the maximum percentage difference was determined in the 100 % < slope class and the minimum percentage difference was determined in the 30-40 % class. For all aspect datasets, the maximum percentage difference was determined in the flat class. The northwest class has the second highest percentage difference. The minimum percentage difference was determined in the southeast class.

Conclusion

Data accuracy is of paramount importance, especially if the data will be used as a basis for planning and application. In large-area studies, data acquisition costs can be considered as important as accuracy. In addition, the detail, precision and volume of the data affect the accuracy of planning as well as the time to analyze. In this context, it is very important to determine the optimals of the data to be used in the study. Generally, the error or difference from the data considered as reference, is measured with point – based approaches. However, such approaches are based on sampling and statistical evaluations are made on the ability to represent the study area. Thanks to the developing technological opportunities, the variety of data sources and accordingly the variety of data continues to increase day by day. In this way, data from different sources with different features and accuracies can be accessed for any field. Thus, it is possible to compare data with different characteristics in the whole study area. Area-based assessments began to be replaced by sampling-based statistics and accuracy assessment techniques. By making such assessments, it is possible to talk about real values instead of confidence level.

Based on the areal analysis results, it is clear that, at least for this study area, for contour lines-based DEM generation, ANUDEM interpolator deliver the most reliable results. However, accuracy rates are similar at 2.5 m, 5m and 10 m resolutions. In this context, 2.5 m and 5 m resolutions can be accepted as superfluous. It should not be forgotten that, every area on the earth has unique topography. The selection of the appropriate interpolation method and the resolution for topographic analysis depends on the precision of the data and the ability to represent the terrain. Therefore, as mentioned by Burrough (1986), “A good GIS should include a range of interpolation techniques that allow the user to choose the most appropriate method for the job at hand”. In this context, according to the results of the analysis selected and applied, the following statements can be made as supported by Chang and Tsai (1991), Toutin (2002), Grohmann (2015) and Szabó *et al.* (2015). The accuracy of the surface model decreases in the case of steeper slopes and also, accuracy of slope and aspect decrease as a DEM resolution decreases.

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Using of high-resolution satellite images in object-based image analysis

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Abstract
Remote Sensing technologies have been used quite a long time in forestry applications. While the more acquired data can be obtained with traditional survey and photogrammetric techniques, they required relatively more manpower and time consuming.
The most important characteristics of this research will bring the new opportunities for forestry applications by using the object-based classification methods with multispectral satellite images that have high spatial resolution (<1meter). In this individual tree and forest stand based research, the solutions searched with using very high-resolution (VHR) satellite images for time-consuming problems in forestry applications.
Keywords: Worldview-2, Object-based image analysis, Tree crown

INTRODUCTION

Remote sensing provides a useful source of data from which updated land-cover information can be extracted for assessing and monitoring vegetation changes. In the past several decades, aerial photo interpretation has played an important role in detailed vegetation mapping (Sandmann and Lertzman, 2003). Nowadays, with the development of technological possibilities, geometric, radiometric, temporal and spectral resolutions in satellite and sensor systems have increased. With these developments, satellite remote sensing data can provide more and variety of information than analog aerial photographs (Yurtseven, 2014).

In remote sensing studies, object-based classification approaches are used in addition to pixel-based classification approaches. The main reason for using object-based approaches is that image objects are characterized by a number of additional features, such as texture and form, beyond the pure spectral information. All this additional information can hardly be exploited using pixel-based approaches (Baatz and Schäpe, 1999; Wong *et al.*, 2003). In object-based image analysis (OBIA), unlike traditional image processing techniques, the smallest processing unit is image objects or segments rather than pixels (Baatz *et al.*, 2004). Unlike pixel-based methods, the image is analyzed in homogeneous segments (objects) by shape, texture and contextual models. This provides a sophisticated base for image analysis (Yan *et al.*, 2006).

OBIA of multispectral (MS) imagery has entered the remote sensing literature at a very early stage (Kettig and Landgrebe, 1976; Haralick, 1983; Haralick and Shapiro, 1985; Levine and Nazif, 1985; Strahler *et al.*, 1986; McKeown Jr *et al.*, 1989; Pal and Pal, 1993; Câmara *et al.*, 1996; Hay *et al.*, 1996; Lobo *et al.*, 1996; Ryherd and Woodcock, 1996; Wulder, 1998; Aplin *et al.*, 1999; Baltsavias, 2004). Multispectral imagery supports not only enhanced display of scene content, but also quantitative analysis based on the intrinsic spectral characteristics of imaged objects (Schott, 2007). In this context, due to the simpler implementation of conventional pixel-based approaches and require less computational power, object-based approaches have not been given due attention (Lobo, 1997). Traditional pixel-oriented algorithms and analytic techniques cannot take full advantage of the increased spatial coherence of very high-resolution imagery (Nussbaum, 2008).

In the literature, it is seen that object-based approaches are generally used to obtain stand-based data in forest areas (Chubey *et al.*, 2006; Wulder *et al.*, 2008; Immitzer *et al.*, 2016; Gudex-Cross *et al.*, 2017). However, the main potential of OBIA is emerged by the use of very high-resolution (VHR) (spectral, radiometric and spatial) imagery (Blaschke *et al.*, 2014). The number of remote sensing systems with very high spatial resolution has increased, as a result of advances in sensor technologies. Therefore, individual tree-based studies can also be performed by using VHR satellite imagery (Ke and Quackenbush, 2007; Li *et al.*, 2015). The acquisition of individual tree crown parameters using VHR data with OBIA techniques is an ongoing research topic. In this context, many techniques have been developed, such as template matching (Pollock, 1996), multiple-scale analysis (Brandtberg and Walter, 1998), valley following (Gougeon, 1995), spatial clustering (Culvenor, 2002), region growing (Erikson, 2003), marked point processes (Perrin *et al.*, 2006), Markov random fields (Descombes and Pechersky, 2006), radial brightness distribution (Pinz, 1989), contour tree (Wu *et al.*, 2016). Most of the proposed algorithms are used combinations of these techniques.

The accuracy of detailed vegetation classification with very high-resolution imagery is highly dependent on the segmentation quality, sample size, sampling method, classification framework, and ground vegetation distribution and mixture (Yu *et al.*, 2006; Rafieyan *et al.*, 2009a; Rafieyan *et al.*, 2009b).

In this study, it is aimed to determine the usage potential of the above-mentioned combination (VHR satellite imagery and OBIA) in forest areas. In this context, WorldView-2 (WV-2) MS imagery were employed. OBIA-based classifications were made on this imagery to generate stand and individual tree based information. Accuracy analyzes were performed to evaluate the problems and dilemmas and all the results were discussed.

Study area and data

The study area is located in north of Istanbul in Turkey and covered western part of the forested area called the Belgrade Forests (Figure 1). Elevations, ranges from the sea level up to 237.17 m. Main species that show stand formation in the study area are: Oak species (*Quercus* sp.), Oriental beech (*Fagus orientalis*), Common hornbeam (*Carpinus betulus*), Anatolian chestnut (*Castanea sativa*), Black pine (*Pinus nigra*), Stone pine (*Pinus pinea*), Turkish pine (*Pinus brutia Ten.*), Maritime pine (*Pinus pinaster*), False acacia (*Robinia pseudoacacia*), Linden species (*Tilia* sp.), Strawberry tree (*Arbutus unedo*) and Oriental spruce (*Picea orientalis*).

In this study, stereoscopically acquired a pair of WV-2 satellite data were used. Data acquisitions were performed on June 6, 2011 at 10:59 (A.M.) (with 10.0 off nadir angle) and 11:00 (A.M.) (with 21.1 off nadir angle) local time. WV-2 imagery have 8 MS and a panchromatic sensor bands (see Table 1 for more details). Further details about the sensor can be found on Updike and Comp (2010).

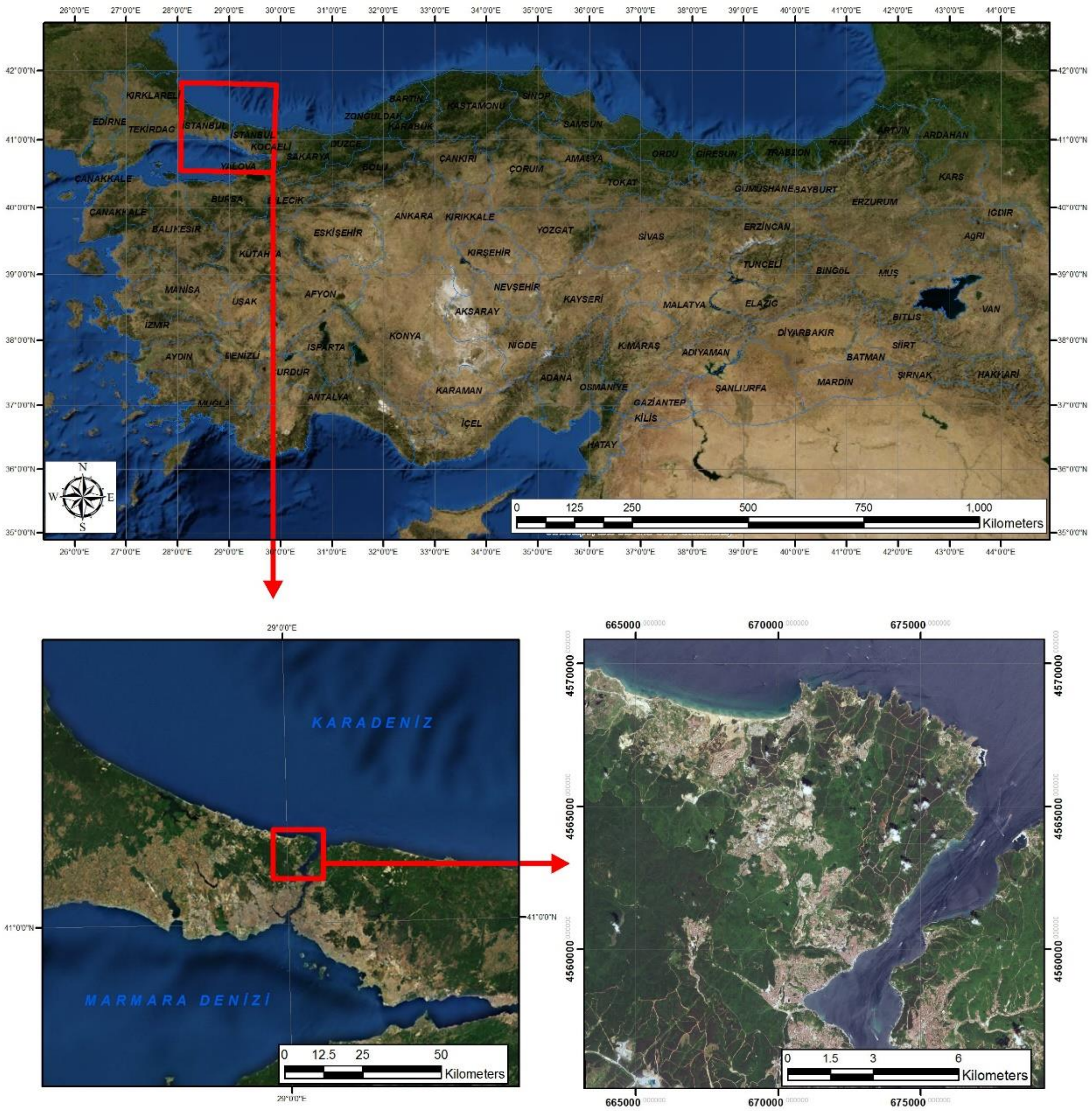

Figure 1. Study area.

Table 1. Characteristics of WorldView-2 imagery.

Spectral Bands	Wavelength (nm)	Spatial Resolution at Nadir Look (m)
Coastal	400 - 450	1.84
Blue	450 - 510	1.84
Green	510 - 580	1.84
Yellow	585 - 625	1.84
Red	630 - 690	1.84
Red Edge	705 - 745	1.84
Near-IR1	770 - 895	1.84
Near-IR2	860 - 1040	1.84
Panchromatic	450 - 800	0.46

Methodology

Within the scope of the study, our approach consists of the following main steps (Figure 2): DSM generation with photogrammetric processing, atmospheric and topographic correction, pan-sharpening, generation of image indices, OBIA and classifications.

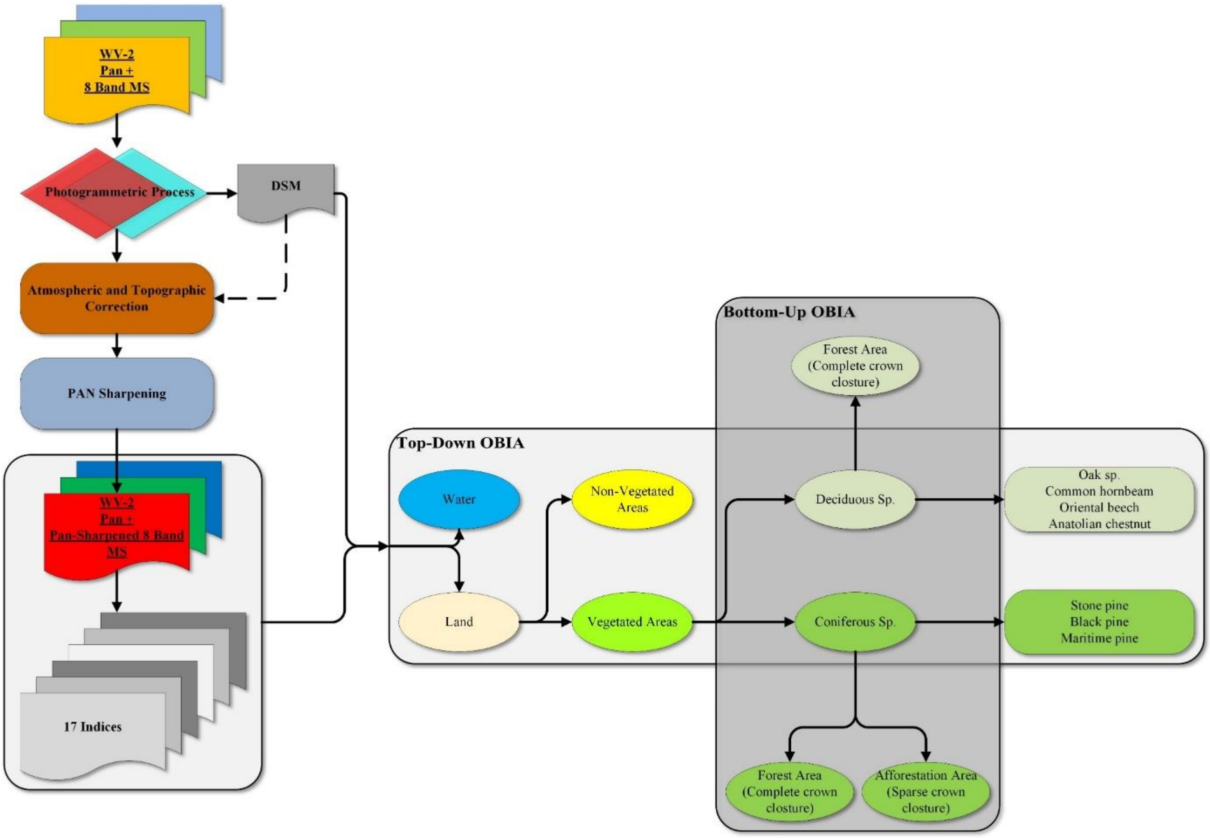

Figure 2. Main workflow steps.

As is known, the basic radiation source of passive remote sensing systems is the sun (Erdin, 1986). Radiation reflected or radiated from the earth reaches the sensors in a manner attenuated by absorption or scattering by atmospheric components (humidity, pressure, temperature, molecular differences) (Bakker *et al.*, 2009). In addition, topographic differences and location on the earth also affect reflection. Elimination of these effects allows accurate evaluation of remote sensing data (Campbell and Wynne, 2012). Especially in VHR satellite imagery, atmospheric and topographic factors adversely affect radiometry (Neubert and Meinel, 2005). Although many different approaches are used in the removal of atmospheric and topographic effects from images, in this study, ATCOR3 model, which provides fast and accurate results, was used to eliminate atmospheric and topographic errors in satellite imagery. Detailed modeling and explanations of the method are described by Richter and Schläpfer (2014). At the stage of atmospheric and topographic corrections, a digital surface model (DSM) is needed. By using state of art technologies such as LIDAR (Light Detection and Ranging) and SAR (Synthetic Aperture Radar), it is possible to generate digital surface and terrain models very precisely. However, in some cases such data may not be accessible for a specific area. Therefore, in this study, DSM has been generated by using stereoscopically acquired panchromatic WV-2 data. In this context, ERDAS Imagine Photogrammetry and Stereo Analyst for ERDAS Imagine software packages were employed to generate DSM.

Spatial resolution is a key feature to obtain detailed information about spatial objects. In this context, spatial resolution should be maximized in order to obtain detailed and precise information. When working with multi-resolution data, resolution merging techniques are used to increase spatial detail. The main interest of merging multi-resolution image data is to generate composite images of improved interpretability (Welch and Ehlers, 1987; Kaczynski *et al.*, 1995; de Béthune *et al.*, 1998). In addition, it is desirable to maintain the spectral quality of the images with the highest possible spatial detail (Cliche *et al.*, 1985). Garguet-Duport *et al.* (1996) indicated that preservation of spectral information and properties is particularly important for vegetation analysis. In this context, the Hyperspherical Color Space (HCS) technique, which was developed specifically for WV-2 satellite data and described by Padwick *et al.* (2010) and Deskevich and Padwick (2012), was used in pan-sharpening process.

Vegetation absorb electromagnetic energy, especially in the part of the spectrum between 450-670 nm wavelengths. This cut is called chlorophyll absorption band. Between 700-1300 nm wavelengths, they reflect about half of the incoming energy. In order to enhance this spectral difference in multi-band employed remote sensing studies, image indices are generated and used in analysis (Sader and Winne, 1992; Koç, 1997; Hayes *et al.*, 2002). When the multispectral data of the WorldView-2 satellite is examined, it is seen that it has suitable spectral characteristics for a total of close to 300 indices including single bands (Henrich *et al.*, 2015). In deciding on the image indices used in the classification, the most commonly used indices in the literature were evaluated for their suitability for the study (Rouse Jr *et al.*, 1974; Tucker, 1979; Jackson *et al.*, 1983; Sellers, 1985; Kaufman and Tanré, 1996; Huete *et al.*, 1997; Wolf, 2010; Jones *et al.*, 2011; Zhou *et al.*, 2012). In this context, 17 image indexes were selected and used in this study (Table 2). After the generation of an input datasets OBIA were performed with the eCognition software. OBIA can be examined in two stages: segmentation and classification. The purpose of the segmentation process is to generate meaningful objects from the image pixels. There are two basic segmentation principles, which are top-down and bottom-up strategies (Trimble, 2012). In the top-down approach, which has been developed on the strategy of dividing objects from smaller pieces into large pieces, the image can be considered as a single large object or it can be applied in previously generated image objects. The bottom-up strategy, in which small objects are combined to form larger objects, is used to generate larger and homogeneous objects than image pixels or previously generated image objects. Classification can be used to generate more meaningful image objects by assisting segmentation, or it can be used for direct classification of generated image objects. In the OBIA processes, various features related to image objects can be used, such as spectral, geometric, positional, textural, and thematic features. Nevertheless, there is no accepted approach in the literature as to which features should be used for classification (Blaschke, 2010).

Results and Discussion

According to the main workflow of this study the first step is photogrammetric analysis and DSM generation. Photogrammetric operations were performed by using rational polynomial coefficients (RPC) parameters, which were supplied with imagery, and 23 ground control points (GCP). GCP coordinates were collected by using NRTK (Network Real Time Kinematic) Global Navigation Satellite System (GNSS) receiver according to the TUREF (Turkish National Reference Frame) TM30 (EPSG: 5254) coordinate system and Turkey CORS (Continuously Operating Reference Stations) network system. In this context, coordinate transformations to WGS 84 geographic coordinates were performed in ArcGIS software. According to the photogrammetric process results aerial triangulation were accomplished with 0.06 m Root Mean Square Error (RMSE) and total RMSE of GCPs were 0.61 m in horizontal plane and 0.52 m in vertical. As a result of photogrammetric operations, 5 m resolution DSM was generated to be used in atmospheric and topographic corrections and OBIA analysis.

Table 2. Description of all indices.

Index Name	**Formula**
Difference Vegetation Index (DVI)	$DVI = (NIR1 - Red)$
Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{(NIR1 - Red)}{(NIR1 + Red)}$
WorldView Improved Normalized Difference Vegetation Index (WVINDVI)	$WVINDVI = \frac{(NIR2 - Red)}{(NIR2 + Red)}$
Renormalized Difference Vegetation Index (RDVI)	$RDVI = \frac{(NIR1 - Red)}{\sqrt{(NIR1 + Red)}}$
Transformed Normalized Difference Vegetation Index (TNDVI)	$TNDVI = \sqrt{\frac{(NIR1 - Red)}{(NIR1 + Red) + 0{,}5}}$
Ratio Vegetation Index (RVI)	$RVI = \frac{Red}{NIR1}$
Iron Oxide (IO)	$IO = \frac{Red}{Blue}$
Soil Adjusted Vegetation Index (SAVI)	$SAVI = \frac{(NIR1 - Red)}{(NIR1 + Red + L)} * (1 + L) \quad L = 0{,}5$
Modified Soil Adjusted Vegetation Index (MSAVI2)	$MSAVI2 = \frac{(2 * NIR1 + 1 - \sqrt{(2 * NIR1 + 1)^2 - 8 * (NIR1 - Red)})}{2}$
Normalized Difference Soil Index (NDSI) – WorldView Soil Index (WVSI)	$NDSI = WVSI = \frac{(Yellow - Green)}{(Yellow + Green)}$
R31	$R31 = \frac{Red\ Edge}{Yellow}$
Simple Ratio Index (SRI)	$SRI = \frac{NIR1}{Red}$
Square Root of Simple Ratio Index (SQRT(SRI))	$SQRT(SRI) = \sqrt{\frac{NIR1}{Red}}$
Normalized Difference Water Index (NDWI) – WorldView Water Index (WVWI)	$NDWI = WVWI = \frac{(NIR2 - Coastal)}{(NIR2 + Coastal)}$
Non-Homogeneous Feature Difference (NHFD)	$NHFD = \frac{(Red\ Edge - Coastal)}{(Red\ Edge + Coastal)}$
Atmospherically Resistant Vegetation Index (ARVI)	$ARVI = \frac{NIR2 - (2Red - Blue)}{NIR2 + (2Red - Blue)}$
Anthocyanin Reflectance Index (ARI)	$ARI = \left(\frac{1}{Green}\right) - \left(\frac{1}{Red}\right)$

Two different WV-2 images covering the same area dated June 6, 2011 were used in the study. The cloud formations in the northern and northeastern regions are especially noteworthy. Although the cloudiness ratios in each image were below 10%, the fact that the cloud formations are fragmented constitutes the biggest negativity in the images. As a result of examinations on the images, approximately 500 hectares of areas were identified which should be masked within the boundaries of the selected study area (areas under the cloud and areas under the cloud shadow). These areas were covered approximately 3% of the study area and were masked out in the imagery at the analysis stage (Figure 3).

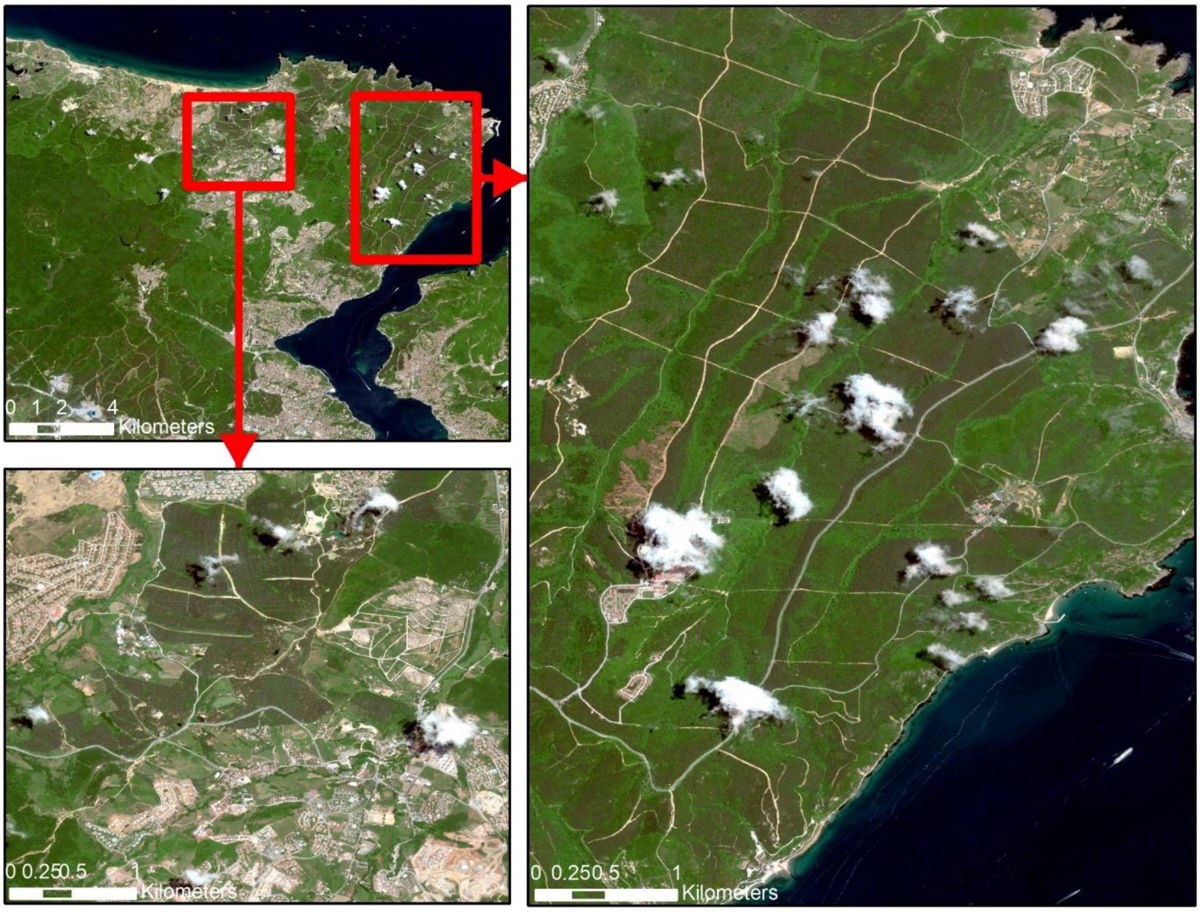

Figure 3. Cloud formations.

Cloud formations were also caused problematic formations on the photogrammetric DSM. In this context, defective areas were corrected by using DEM data, which were generated by the Greater Municipality of Istanbul (Figure 4).

The generated DSM and DSM derived slope, aspect, skyview and shadow data were employed in ATCOR3 and atmospheric and topographic correction operations were performed. The other ATCOR3 input parameters are presented in Table 3. According to ATCOR3 results, 73.2 % of image land pixels were clear land, 26.8 % image land pixels were hazy land and 32 % of image area excluded which are clouds and water bodies.

After the completion of atmospheric and topographic correction processes, pan-sharpening process was performed. At this stage, HCS resolution merge and some image enhancement techniques were combined, to achieve the highest possible spatial resolution and the highest possible spectral separability. As a result of the intensive studies carried out at this stage, application of the following methodological combination were accepted in resolution merge process (Figure 5).

As mentioned by Lillesand *et al.* (2014) the goal of image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between the features in the scene. With the methodological combination applied in this context, the spatial resolution of multispectral data increased from 2 m to 0.25 m, while the interpretability of the imagery was increased (Figure 6). In addition, the file size of the pan-sharpened multispectral data increased to 120 GB. Therefore, a high processing power is required during the processing of the imagery.

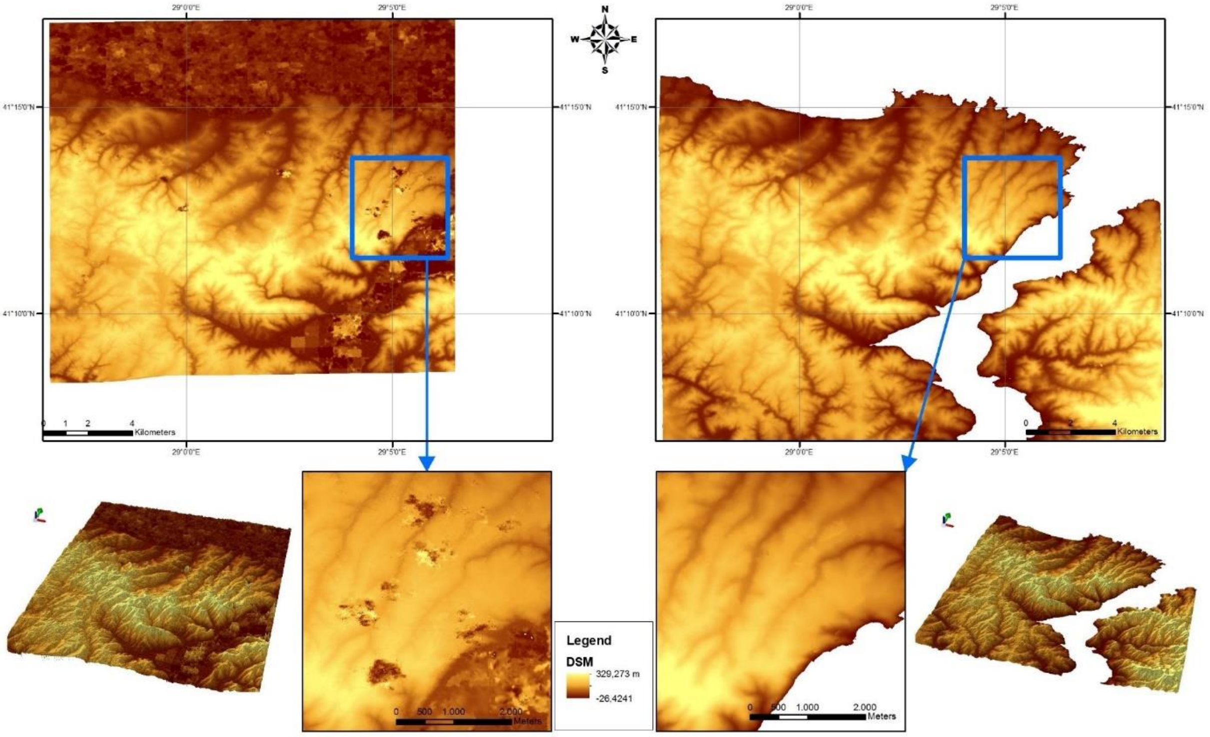

Figure 4. Photogrammetric uncorrected DSM (Left), Corrected DSM (Right).

Table 3. ATCOR3 parameters.

Parameter	Value
Sensor	WorldView-2 MS
Solar Zenith Angle	20,8 °
Solar Azimuth Angle	148,7 °
Sensor Tilt Angle	21,1 °
Satellite Azimuth Angle	175,3 °
Scene Visibility	59
Model for Solar Region	Urban / Midlat Summer Urban
Haze Removal	Yes
Cloud Threshold	16
Water Threshold	4

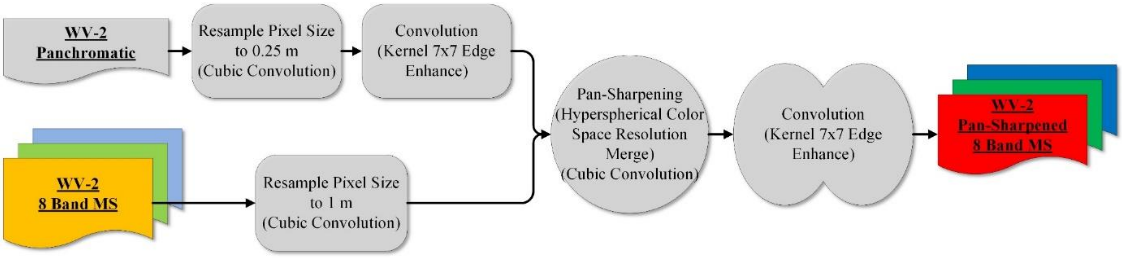

Figure 5. Pan-sharpening and image enhancement processes.

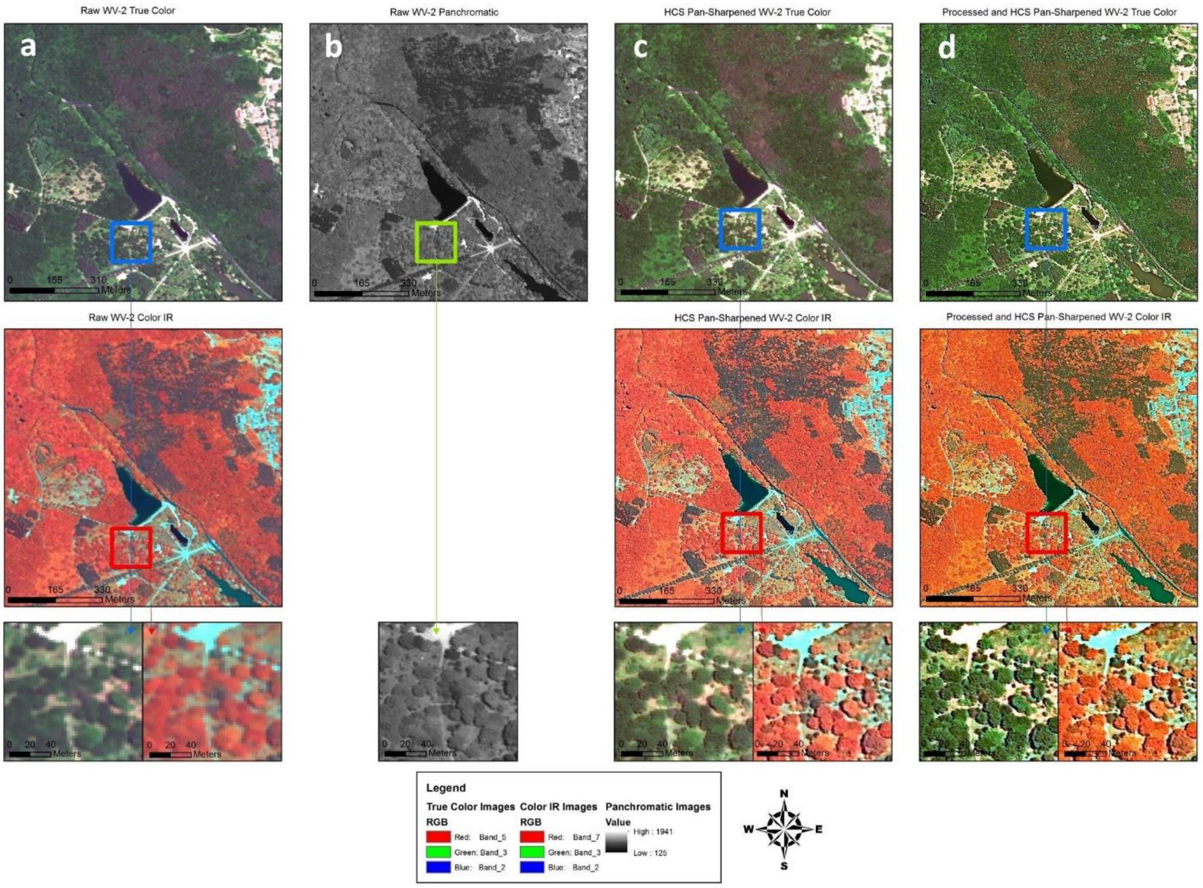

Figure 6. Detail comparisons of raw MS (a), panchromatic (b), standard HCS (c) and the enhancement combined HCS (d) imagery.

After the preparation of the images for the analysis process, we proceeded to the OBIA stage. Since there is no standard method followed in the OBIA operation, according to the data and the desired outputs at the end of the study, the algorithm combinations and workflow are created according to the knowledge and ability of the operator (Navulur, 2007; Blaschke *et al.*, 2008). At this stage, it was decided to use two different approaches in the study, which are top-down and bottom-up strategies. With the top-down approach, it was aimed to obtain stand or species -based information by a hierarchical classification strategy. Differently, with the bottom-up approach, it was aimed to obtain information on individual tree basis in specifically selected areas. However, in the selection of specific areas the data obtained with the top-down approach were used to serve the bottom-up approach (Figure 2).

Before the OBIA, 17 image indexes were generated to support the classification (Appendix 1-Image Indices). The selection of the bands and coefficients to be used in segmentation and classification stages requires a very intensive study. The parameters to be used in these stages were decided by test-observe-interpret combination. In this context, the best combination of band and parameter was determined for each class and classifications were made.

In accordance with the hierarchical model, firstly, land, water and vegetation areas were classified. Imagery were segmented by multiresolution and spectral difference segmentation to generate image objects to be used in the classification. A total of 141 training object were selected in three different classes within the study area. 47 of these are for Land, 84 for Vegetation and 10 for Water class. In this context classifications were accomplished with 99.27% overall classification accuracy and 0.9889 Kappa (Figure 7).

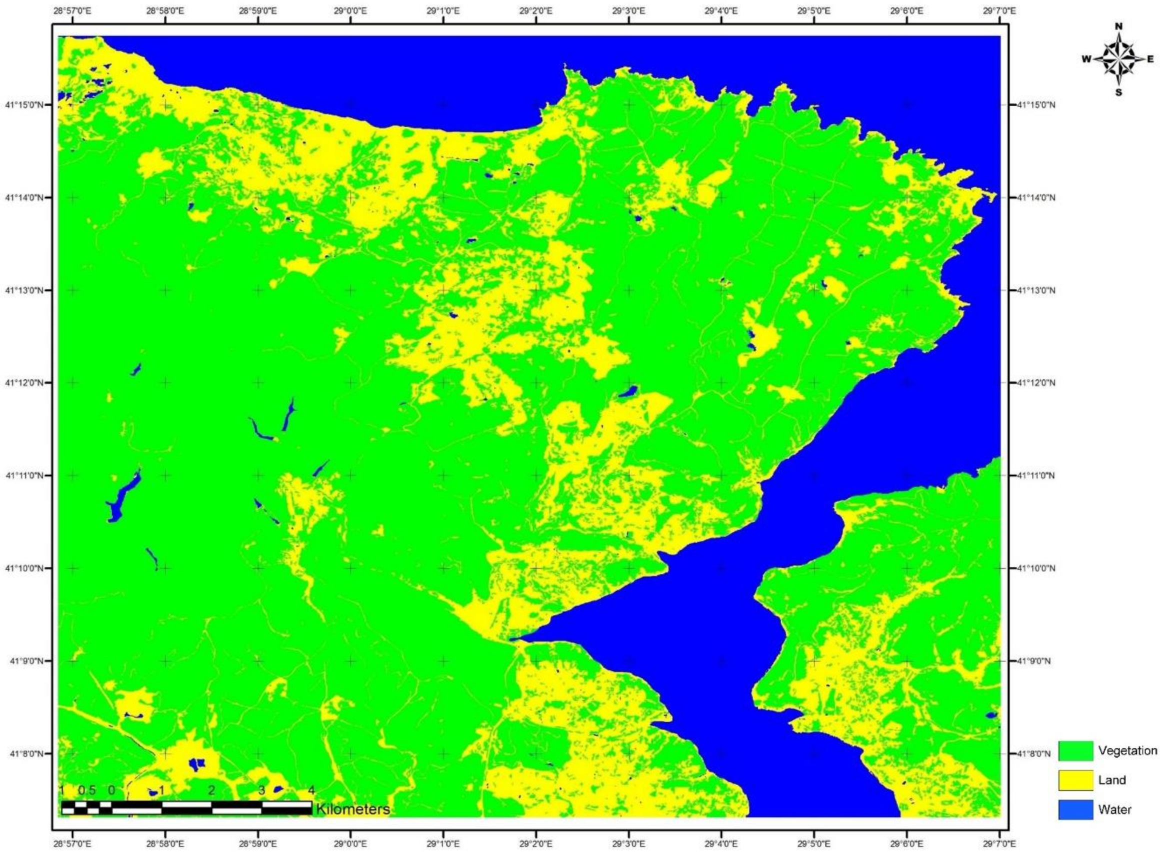

Figure 7. Land, water and vegetation classification results.

In the second step, deciduous, coniferous and shrub classifications were made (Figure 8). In this context, overall classification accuracy and Kappa statistic were obtained as 99.33% and 0.99 respectively.

In the final step, a class has been established for each species with a proportionately greater than 5 percent area in the study area. In this context, Oak sp., anatolian chesnut, oriental beech, common hornbeam, black pine, maritime pine and stone pine stands were classified. However, black pine and maritime pine stands which are spectrally similar and lower the classification accuracy were evaluated in a single class. After the classifications, water bodies and land classes were merged to the obtained thematic data and accuracy assessments were made for 8 classes (Table 4, Figure 9).

As mentioned before, by using the bottom-up approach, the generability of individual tree-based information were examined. In this context, three different scenario or forest stand structure were evaluated. Individual trees were classified and accuracy assessments were performed. The number of trees obtained by stereoscopic interpretation was used as a reference in the accuracy assessment stage.

First plot site was selected in a coniferous (Maritime pine) forest with complete crown closure. Using a multi-stage classification method, top point of each trees and the gaps between trees were determined. In addition, an iterative algorithm was prepared using bottom-up segmentation technique and the crown boundaries were determined (Figure 10). According to accuracy assessment results overall classification accuracy was obtained as 94.74% (Table 5).

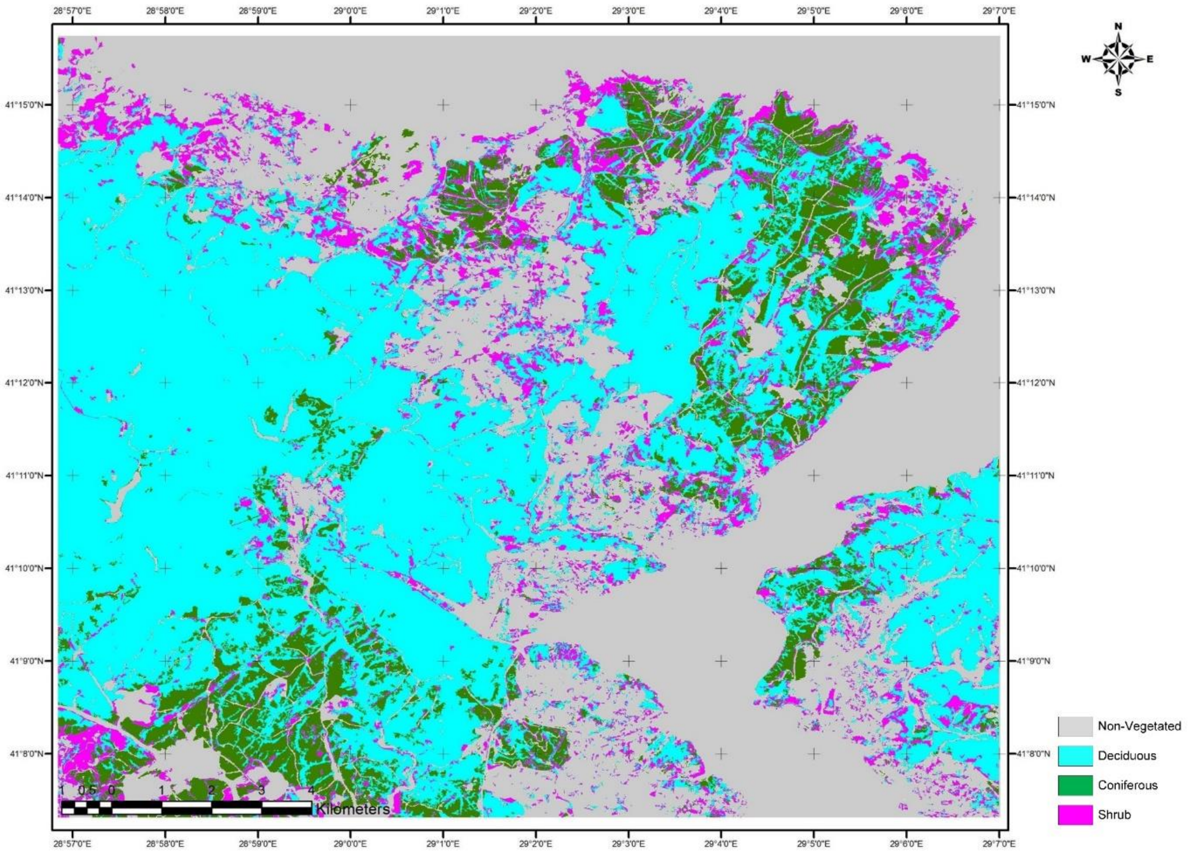

Figure 8. Deciduous, coniferous and shrub classification results.

Table 4. Classification accuracies for all classes.

Class name	Producer's Accuracy	User's Accuracy	Kappa
Land	100.00%	100.00%	1.0000
Water bodies	100.00%	100.00%	1.0000
Oak sp.	100.00%	100.00%	1.0000
Anatolian chesnut	89.47%	94.44%	0.9360
Oriental beech	94.44%	94.44%	0.9365
Common hornbeam	88.24%	83.33%	0.8110
Black pine - Maritime pine	94.44%	94.44%	0.9365
Stone pine	94.44%	94.44%	0.9365
Overall Classification Accuracy		95.14%	
Overall Kappa Statistics		0.9444	

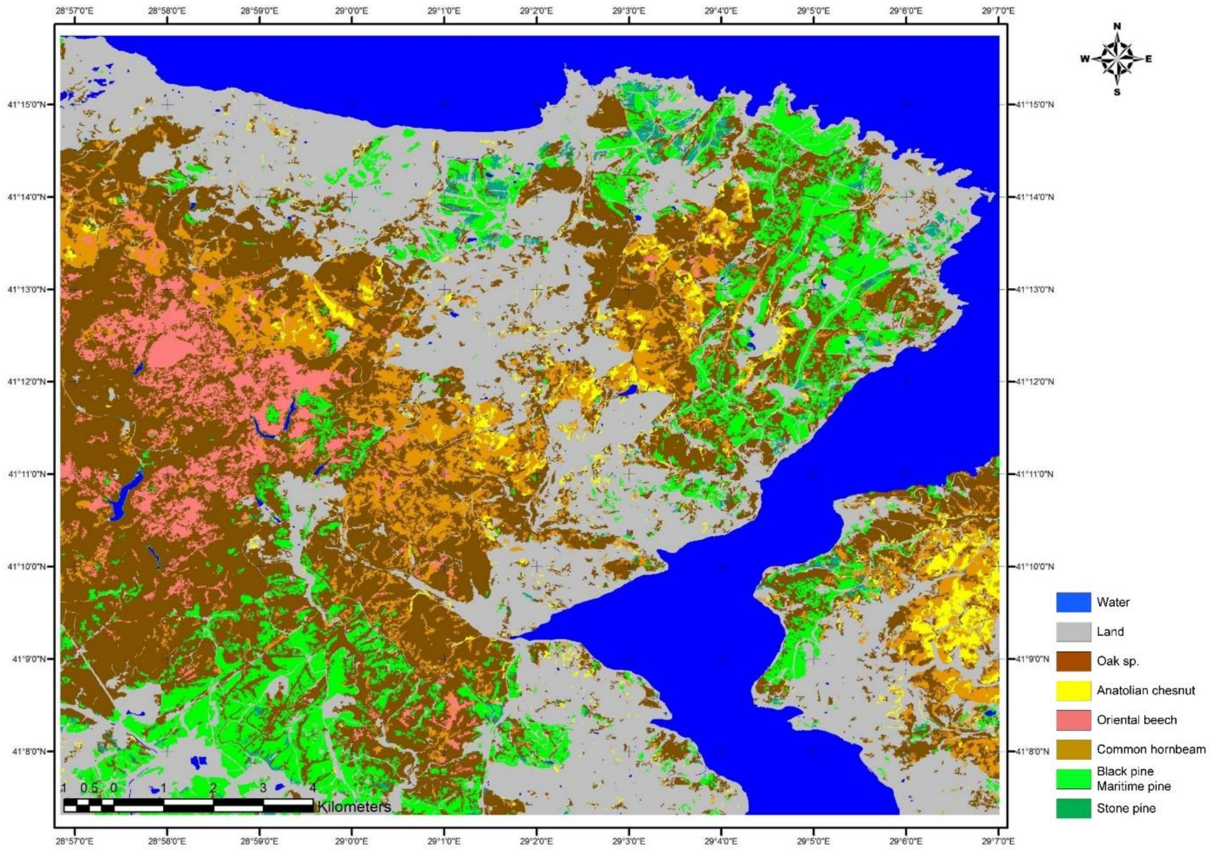

Figure 9. Classification results for all classes.

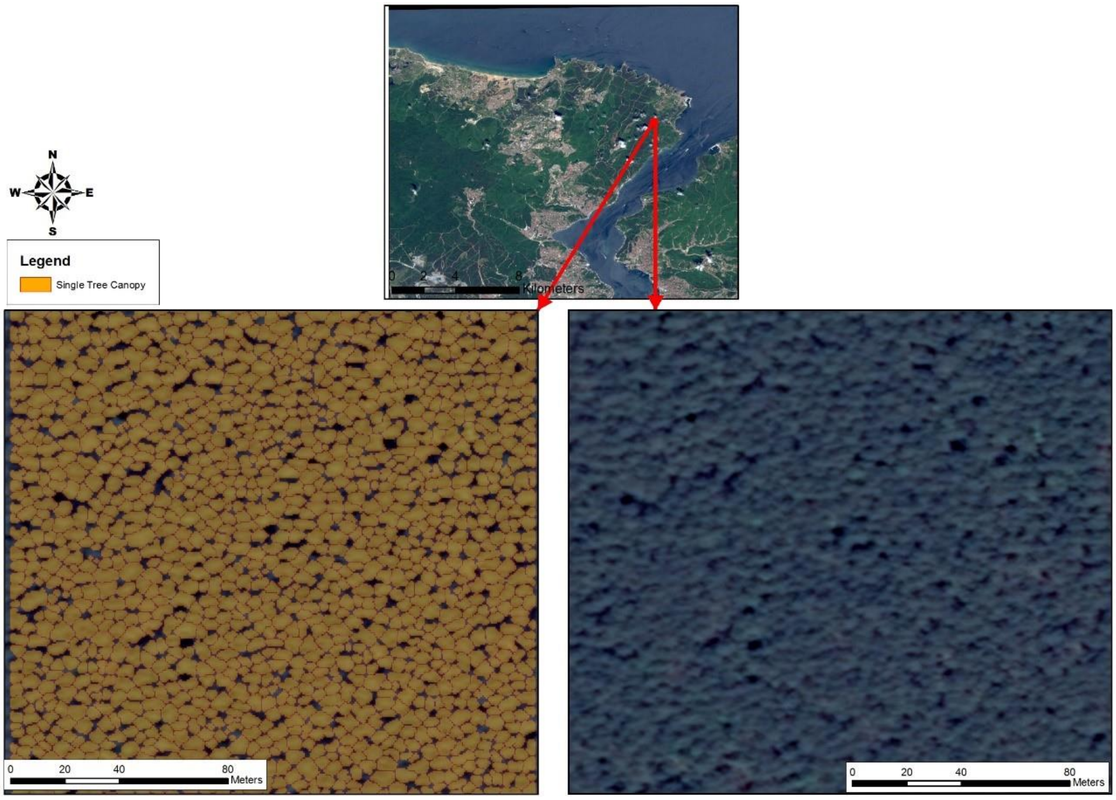

Figure 10. Classification of coniferous (Maritime pine) forest with complete crown closure.

Table 5. Accuracy assessment result of coniferous (Maritime pine) forest with complete crown closure.

Number of trees obtained by photogrammetric evaluations	Total number of trees as a result of classification	Number of extra trees that do not actually exist	Number of trees that cannot actually be detected	Total Number of Incorrectly Classified Trees
228	232	10	6	16

Overall Classification Accuracy	94,74%
Error of Omission	6,90%
Producer's accuracy	93,10%

Second plot site was selected in a coniferous (Stone pine) forest with sparse crown closure. Using a multi-stage classification method, bare earth, highway, leafy and coniferous trees were classified separately. Similarly to the first plot site, an iterative algorithm was prepared using bottom-up segmentation technique and the crown boundaries were determined (Figure 11). According to accuracy assessment results overall classification accuracy was obtained as 100% (Table 6).

Figure 11. Classification of coniferous (Stone pine) forest with sparse crown closure

Conclusions

The main purpose of this study is to investigate what data can be obtained from high resolution satellite data by using object-oriented image analysis methods for forestry purposes. In the context of this study, the most important point encountered during the study and the literature research was the lack of a standard workflow in the object-based image analysis method. Therefore, the user has to decide the

Table 6. Accuracy assessment result of coniferous (Stone pine) forest with sparse crown closure

Number of trees obtained by photogrammetric evaluations	Total number of trees as a result of classification	Number of extra trees that do not actually exist	Number of trees that cannot actually be detected	Total Number of Incorrectly Classified Trees
264	267	3	0	3
Overall Classification Accuracy	100,00%			
Error of Omission	1,12%			
Producer's accuracy	98,88%			

appropriate methods according to the data and the desired outputs. The preparation of rule sets with a high classification accuracy depends entirely on the operator's knowledge and experience.

The final plot site was selected in a deciduous (Oak sp., Oriental beech, Common hornbeam) forest with complete crown closure. Despite all the evaluations, it was not possible to obtain individual tree based data for forest areas in this structure (Figure 12). The main reason of this situation was considered as the sympodial branching of deciduous species.

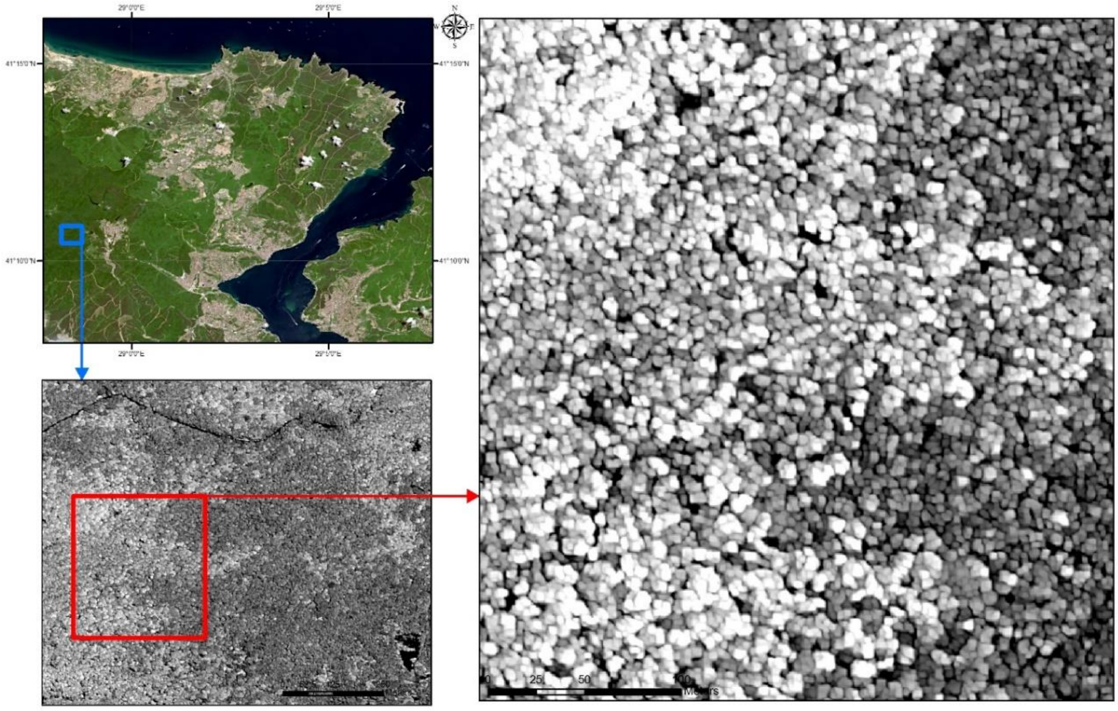

Figure 12. Image objects of deciduous forest with complete crown closure

In the decision-making process, the user needs to know the attributes of the objects he / she is working on, as well as which variables will be defined in a mathematical model. One of the findings obtained from the study is that the rule sets prepared for a specific object or class give much more accurate results than the rule sets prepared for obtaining many objects. In addition, it has been found that the preparation and implementation of such rule sets are more efficient.

In accordance with the results presented in the study, data, which are very important in terms of forestry such as number of trees per hectare and tree crown width, were obtained with satisfactory accuracy by using OBIA and VHR satellite imagery.

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