Effects of land-use regime on soil erodibility indices and soil properties in Unye, Turkey

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EFFECTS OF LAND-USE REGIME ON SOIL ERODIBILITY INDICES AND SOIL PROPERTIES IN UNYE, TURKEY

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SUMMARY

We evaluated the effects of land-use regime on soil erodibility indices and several soil properties in forested, deforested, and cultivated areas in the village of Unye, Turkey. Twelve sample plots (spaced 150 m apart) with northern aspects were established in each land-use regime, and samples were taken at soil depths of 0–20, 20–50, and 50–80 cm. Soil organic matter (SOM), soil reaction (pH), total lime ($CaCO_3$), texture (sand, silt, and clay), dispersion ratio (DR), erosion ratio (ER), colloid-moisture equivalent ratio (C-MER), structural stability index (SSI), field capacity (FC), wilting point (WP), and available water capacity (AWC) were analyzed. The average (of the three soil depths) AWC, FC, and WP values were not affected by the site, although site, soil depth, or both significantly affected other analyzed soil variables. Deforestation and subsequent tillage practices resulted in an almost 20% decrease in clay content, a 33% decrease in SOM, a 15% decrease in AWC, a 51% decrease in total $CaCO_3$, a 24% decrease in SSI, a 60% increase in DR, and a 98% increase in ER relative to undisturbed forest soil. At cultivated and forested sites, the ER and DR increased with increasing soil depth. At deforested sites, ER and DR were lowest at 50–80 cm. SOM was the highest at 0–20 cm in the forested sites. Decreasing SOM, clay content, and SSI, as well as increasing DR and ER were outcomes of deforestation. These results indicate that the conversion of forest into cropland deteriorates some soil properties, especially SOM and SSI, and alters the stability of soil aggregates, thus increasing the susceptibility of deforested sites to erosion.

KEYWORDS:
Land use, soil erosion, soil properties, Turkey.

INTRODUCTION

One of the most important issues in Turkish forestry is forest degradation and subsequent forest clearing. The natural forest ecosystems of the eastern Black Sea region are excessively devastated relative to other forested regions in Turkey. This area of fairly high and steep mountains receives significant precipitation and is intensively populated. The main causes of forest devastation in this region are tillage practices and cultivation (tea or hazelnut) in lower elevation sub-regions (600–1200 m), and transhumance (cultivation of grass and meadow vent, and provision of combustion material) in higher regions of forested areas (1200–1700 m).

Soils in Turkey are increasingly susceptible to erosion owing to the conversion of forests to croplands. Land-use regimes affect soil properties and soil susceptibility to erosion, and deforestation and subsequent tillage practices can change the stability of soil aggregates and deteriorate soil properties [1-5]. According to Knuti et al. [6], agricultural practices in forest areas damage soil quality and increase soil erosion. Boyle [7] and Mroz et al. [8] stated that total tree harvesting may have several negative effects on forest soils, including nutrient removal in the harvested material, increased erosion rates or percolation losses of nutrients, and soil compaction. Likens et al. [9] reported on extensive nutrient losses (particularly of NO_3-N and Ca) following deforestation. Conversion of forest and grassland into agricultural land is of considerable concern worldwide in the context of environmental degradation and global climate change [10, 11]. Deforestation also has important consequences for water conservation [2].

The objectives of this study were to examine the effect of land-use regime on soil erodibility indices and other properties, and to evaluate the changes in soil properties resulting from deforestation or cultivation in the village of Unye, Turkey.

MATERIALS AND METHODS

The study was conducted in the village of Unye, on the northeastern coast of Turkey (41°08′–41°05′ N, 37°09′–

37°21′ E). The study area of about 260 ha extends in the east-west direction, of which 34.6% is deforested which has been clear-cut about 20 years ago and cultivated until now. An additional 30.7% has been under cultivation for many years, and the remainder of the study area is maintained as forest. The elevation of the site ranges from 150 to 650 m above sea level. The landscape in the area faces north, with a slope ranging from 30 to 50%. The region is characterized by a warm and humid Black Sea climate. Mean annual rainfall is approximately 1100 mm, and 60% of which falls in autumn and winter months. The mean annual temperature is 13.4 °C [12].

Fagus orientalis, *Carpinus orientalis*, and *Quercus* spp. are the predominant tree species in the forested area. Fruits and vegetables (e.g., corn, potato, cabbage) and hazelnuts are common crops in the cultivated parts of the study area. As is common in this region, *Fagus orientalis* and *Quercus* spp. were the predominant vegetation in the area prior to deforestation; the vegetation was cleared approximately 20 years ago, and these sites have commonly been used for hazelnut cultivation.

Soil sampling and analyses

Soils were examined from three different land-use regimes (forested, deforested, and cultivated). From each site, 12 samples located 150 m apart were systematically collected for detailed analysis. The samples were taken from three soil depths, 0–20, 20–50, and 50–80 cm, at each site.

Particle size distribution and soil organic carbon were determined using disturbed soil samples passed through a 2-mm sieve using the Bouyoucos hydrometer method [13, 14] and the modified Walkley-Black wet oxidation procedure, respectively. Soil organic matter (SOM) was calculated by multiplying soil organic carbon by 1.72 [15, 16]. Calcium carbonate content ($CaCO_3$) and soil acidity (pH) were measured using the procedures outlined by Arp [16] and Page et al. [17]. Dispersion ratio (DR) was determined according to the methods described by Middleton [18]. Total clay (TC) and total silt (TS) contents were determined from the particle size distribution using the hydrometer method [19]. The clay and silt fractions obtained by chemical dispersion were taken as TC and TS, while water-dispersible clay and silt (WDCS) was obtained as above, except that no chemical dispersant was used. Colloid-moisture equivalent ratio (C-MER) and erosion ratio (ER) [20], field capacity (FC), wilting point (WP), available water capacity (AWC) [21], and structural stability index (SSI) [22] were also determined.

Statistical analyses

Analyses of variance (ANOVA) were performed to determine the effects of land-use regime and soil depth on the chemical and physical properties of the soil. Arcsine transformation was performed on percentage data, but the means based on the original measurements are presented in the tables. Significant differences between variables were determined by Duncan's new multiple range test. Statistical analyses were performed using SPSS.

RESULTS AND DISCUSSION

ANOVA revealed significant differences among the sites and soil depths, or both, for sand, silt, clay, DR, ER, C-MER, SSI, SOM, pH, and total $CaCO_3$ ($p<0.05$) (Tables 1 and 2). FC and WP were not significantly affected by site or soil depth.

The sand, silt, and clay contents averaged across the three soil depths showed significant differences among sites, but there were no significant differences in sand, silt, and clay contents among soil depths at each site (Tables 1 and 2). The average sand content was significantly higher at the deforested site than at the other two sites (67.6%, 73.3%, and 67.1% for the cultivated, deforested, and forested lands, respectively). The average silt content (of all three depths) was highest in the forested soil, and the clay content was higher in the forested and cultivated sites (Table 1).

More clay accumulated at lower depths (20–80 cm) in the cultivated and forested sites. However, the soils at the deforested site had a higher sand content and lower clay content (17.5 to 18.4%) at each depth (Table 2). This may be the result of translocation of finer particles to lower depths (>80 cm), or the movement of finer particles to other areas via erosion, thus leaving the coarser particles in the soils of the deforested site. This scenario is supported by ER and DR results; the average ER and DR values were highest in the deforested site at 0–50 cm. ER and DR increased with soil depth at the cultivated and forested sites, but were lowest in the 50–80 cm soil depth at the deforested site. When averaged over the three soil depths, DR and ER were highest at the deforested site (12.1% and 28.4%, respectively). Soil depth also significantly affected DR and ER. Compared to the soil surface (0–20 cm) at the cultivated and forested sites, the deeper soils had higher DR and ER. The 50–80 cm deep soils at the deforested site had the lowest DR and ER values, 10.1% and 25.0%, respectively (Table 2).

According to Karagül [3], DR and susceptibility to erosion were higher at lower soil depths. In our study, increases in clay content at 50–80 cm depths in the forest and cultivated sites may have caused higher DR at the shallower depths. Nkana and Tonye [4] found that soil sand content was significantly affected by site, and cultivated lands usually have higher sand content in the surface soils than forested sites. As in our study, Hajabbasi et al. [2] found a higher clay content at lower soil depths (30–130 cm) in de-graded and cultivated sites; however, in contrast to our fin-dings, they indicated that clay content was higher in the upper soils (0–30 cm) of a forested site. Some studies have reported higher clay content in cultivated sites [3, 23, 24], whereas Celik [5] found higher clay levels in a forested site. In our study, clay content was higher in the cultivated and forest sites than in the deforested site, and there was no significant difference between cultivated and forested sites. Decreases in clay content and increases in sand content during the last 25 years at the degraded site in our study could increase the susceptibility of this site to erosion.

Similar to our study, Korkanç [25] and Karagül [3] found a lower DR in forested sites than in cultivated ones. When DR was lower than 10%, soil susceptibility to erosion was low [20, 26]. We found the average DR to be lower than 10% in the forested and cultivated sites, but higher than 10% at all depths in the deforested site. Thus, susceptibility to erosion was higher at the deforested site than at the other two sites. High DR and low C-MER resulted in high ER, as found by Korkanç [25]. High levels of SOM at the forested site resulted in low DR and lower susceptibility to erosion, as reported by Balcı [27] and Karagül [3].

Although site and soil depth did not significantly affect FC and WP, the deeper soils (20–50 and 50–80 cm) had a lower WP (26.1% and 25.4%, respectively) relative to the surface soil (0–20 cm; 30.1%) at the forested site (Table 2). However, WP at the cultivated and deforested sites was lowest in the surface soils (0–20 cm; 27.9% and 25.9%, respectively).

The average FC values (of the three soil depths) were 37.3%, 36.7%, and 35.9% for the cultivated, deforested, and forested sites, respectively. A higher FC was found at the lower depths (20–50 and 50–80 cm) in the cultivated and forested sites, but FC was higher in the surface soils at the deforested site, as with WP.

No significant difference was found between the sites in average AWC (8.26%, 7.20%, and 8.44% for the cultivated, deforested, and forested sites, respectively; Table 1). Soil depth, however, did affect AWC; at the 50–80 cm

TABLE 1 - Effect of land-use regime on soil properties.

Soil property**	Land-use regime	Mean	Standard Deviation	F-ratio	Significance Level
	Cultivated	67.6 b*	9.27		
Sand (%)	Deforested	73.3 a	9.64	4.85	0.010
	Forested	67.1 b	8.90		
	Cultivated	9.5 b	2.97		
Silt (%)	Deforested	9.0 b	3.26	3.54	0.033
	Forested	10.9 a	3.76		
	Cultivated	22.9 a	8.25		
Clay (%)	Deforested	17.7 b	8.34	3.36	0.038
	Forested	22.0 a	10.4		
	Cultivated	9.35 b	4.13		
DR (%)	Deforested	12.1 a	5.52	6.02	0.003
	Forested	7.55 b	6.38		
	Cultivated	16.5 b	7.55		
ER (%)	Deforested	28.4 a	17.2	10.51	0.000
	Forested	14.3 b	15.2		
	Cultivated	0.60 a	0.14		
C-MER	Deforested	0.48 b	0.30	6.56	0.002
	Forested	0.59 a	0.20		
	Cultivated	27.5 a	8.47		
SSI (%)	Deforested	22.3 b	7.46	7.64	0.001
	Forested	29.2 a	7.06		
	Cultivated	37.3 a	9.96		
FC (%)	Deforested	36.7 a	12.17	0.15	0.861
	Forested	35.9 a	6.54		
	Cultivated	28.98 a	9.74		
WP (%)	Deforested	29.55 a	11.47	0.40	0.672
	Forested	27.43 a	7.23		
	Cultivated	8.26 a	3.15		
AWC (%)	Deforested	7.20 a	3.48	1.26	0.288
	Forested	8.44 a	4.14		
	Cultivated	1.78 b	1.24		
SOM (%)	Deforested	2.08 b	0.88	6.40	0.002
	Forested	3.09 a	2.27		
	Cultivated	6.72 a	0.71		
pH	Deforested	6.35 b	0.70	3.88	0.024
	Forested	6.28 b	0.65		
	Cultivated	10.1 b	17.78		
$CaCO_3$ (%)	Deforested	2.59 ab	5.30	2.87	0.041
	Forested	5.26 a	14.31		

DR: dispersion ratio, ER: erosion ratio, C-MER: colloid-moisture equivalent ratio, SSI: structural stability index, FC: field capacity, WP: wilting point, AWC: available water capacity, SOM: soil organic matter. *: Means in a row followed by the same letter are not significantly different at p<0.05. ** Values are the averages obtained from three depths (0–20, 20–50 and 50–80 cm).

TABLE 2 - Effect of land-use regime and soil depth on soil properties.

Land-use regime	Depth (cm)	Soil property	Mean	Std. Dev.	F-ratio	Sig. Level	Soil property	Mean	Std. Dev.	F-ratio	Sig. Level
Cultivated	0–20	Sand (%)	69.7 a	10.23	1.34	0.24	SSI (%)	26.4 a	8.41	1.90	0.68
	20–50		67.0 a	8.98				28.7 a	7.73		
	50–80		66.4 a	9.04				27.6 a	9.92		
Deforested	0–20		73.3 a	8.91				22.0 a	6.56		
	20–50		72.3 a	8.94				23.0 a	6.88		
	50–80		74.3 a	11.53				22.0 a	9.26		
Forested	0–20		67.9 a	8.84				29.3 a	7.54		
	20–50		67.4 a	8.14				28.7 a	5.96		
	50–80		65.6 a	10.79				29.8 a	8.48		
Cultivated	0–20	Silt (%)	9.8 a	4.13	1.63	0.13	FC (%)	34.1 a	9.62	0.51	0.84
	20–50		9.1 a	2.61				37.9 a	10.06		
	50–80		9.4 a	1.92				40.0 a	10.16		
Deforested	0–20		9.2 a	2.81				34.3 a	9.17		
	20–50		10.3 a	3.20				37.0 a	11.89		
	50–80		7.3 a	3.31				38.8 a	15.25		
Forested	0–20		11.6 a	3.36				37.5 a	7.06		
	20–50		10.9 a	3.46				34.7 a	6.15		
	50–80		10.4 a	4.95				35.2 a	6.69		
Cultivated	0–20	Clay (%)	20.5 a	8.63	1.06	0.40	WP (%)	27.9 a	10.29	0.67	0.71
	20–50		24.0 a	7.92				29.1 a	9.71		
	50–80		24.2 a	8.44				30.0 a	10.0		
Deforested	0–20		17.5 a	8.20				25.9 a	7.44		
	20–50		17.5 a	8.09				30.1 a	11.5		
	50–80		18.4 a	9.33				32.7 a	14.2		
Forested	0–20		20.5 a	10.67				30.1 a	6.91		
	20–50		21.6 a	9.63				26.1 a	7.16		
	50–80		24.0 a	12.20				25.4 a	7.56		
Cultivated	0–20	DR (%)	8.6 ab	2.18	2.16	0.04	AWC (%)	6.1 a	2.61	1.97	0.58
	20–50		9.4 ab	3.21				8.8 a	2.22		
	50–80		10.2 ab	6.38				10.0 a	3.52		
Deforested	0–20		13.2 a	5.93				8.5 a	4.83		
	20–50		12.8 a	5.80				7.0 a	1.95		
	50–80		10.1 ab	4.70				6.1 a	2.86		
Forested	0–20		5.6 b	4.00				7.4 a	3.63		
	20–50		8.4 ab	7.45				8.5 a	4.26		
	50–80		9.2 ab	7.68				9.8 a	4.75		
Cultivated	0–20	ER (%)	16.0 b	6.42	2.70	0.01	SOM (%)	3.19 b	1.01	9.45	0.00
	20–50		15.6 b	5.91				1.20 e	0.61		
	50–80		18.0 ab	10.43				0.92 bcd	0.49		
Deforested	0–20		29.9 a	18.48				2.72 bcd	0.64		
	20–50		30.4 a	16.79				1.86 de	0.91		
	50–80		25.0 ab	17.41				1.66 de	0.76		
Forested	0–20		12.8 b	12.31				4.48 a	2.91		
	20–50		15.2 b	18.08				2.82 bc	1.37		
	50–80		15.4 b	16.96				1.52 e	0.40		
Cultivated	0–20	C-MER (%)	0.58 abc	0.13	2.15	0.04	pH	6.55 a	0.49	1.16	0.33
	20–50		0.63 ab	0.14				6.75 a	0.80		
	50–80		0.60 abc	0.16				6.90 a	0.84		
Deforested	0–20		0.50 bc	0.13				6.31 a	0.70		
	20–50		0.47 bc	0.14				6.32 a	0.71		
	50–80		0.48 bc	0.15				6.45 a	0.77		
Forested	0–20		0.52 abc	0.19				6.22 a	0.69		
	20–50		0.61 abc	0.18				6.33 a	0.62		
	50–80		0.58 abc	0.13				6.34 a	0.74		
Cultivated	0–20	CaCO3 (%)	7.0 a	11.6	0.86	0.55					
	20–50		10.9 a	20.1							
	50–80		12.5 a	21.2							
Deforested	0–20		3.6 a	7.8							
	20–50		2.3 a	4.2							
	50–80		1.8 a	3.2							
Forested	0–20		3.4 a	10.2							
	20–50		6.7 a	17.1							
	50–80		6.0 a	16.7							

DR: dispersion ratio, ER: erosion ratio, C-MER: colloid-moisture equivalent ratio, SSI: structural stability index, FC: field capacity, WP: wilting point, AWC: available water capacity, SOM: soil organic matter. *: Means in a column with the same letter are not significantly different at $p<0.05$.

depth, the cultivated and forested sites had significantly high AWCs. Relative to the surface soils (0–20 cm; 8.5%) at the deforested site, the deeper soils (20–50 and 50–80 cm) were characterized by lower AWC (7.0% and 6.1% respectively). However, AWC was lowest in the surface soils of the cultivated and forested sites (Table 2). Although there were no significant differences among sites in our study, AWC was higher in the forested area, as found by Karagul [3]. The high SOM content in the forest soil may have increased the soil AWC, as noted in previous studies [28-30].

The average C-MER was lowest in the deforested site (0.48%; Table 1). The C-MER values indicated a difference between land use regimes (Table 2), and deforested sites had the lowest C-MER for all three soil depths. According to Özhan [16], soils with C-MER values lower than 1.5% are susceptible to erosion. In this study, all sites had C-MER values below this threshold, indicating soil susceptibility to erosion.

SSI was significantly affected by site, but not by soil depth (Tables 1 and 2). The deforested site had the lowest average SSI across the three depths (22.3%), and average SSI was found to be 27.5% and 29.2% for the cultivated and forested sites, respectively. A high soil SSI reduces susceptibility to erosion [22]. Doğan and Güçer [31] and Aşkın [32] found that soils with an SSI lower than 40% were more susceptible to erosion.

$CaCO_3$ was significantly affected by site and soil depth. The average $CaCO_3$ across the three depths was highest at the cultivated site (10.1%) and lowest at the deforested site (2.59%). High $CaCO_3$ can increase aggregate size in soil and reduce erosion.

Soil pH was significantly affected by site, and the average pH across the three soil depths was highest at the cultivated site (6.72). Although not significantly affected by soil depth, pH increased in the lower depths at all three sites. The forest at 0–20 cm had the lowest pH (6.22). In a cultivated site, after forest removal, pH usually does not change, and SOM decreases over time [33]. At our cultivated sites, pH was not too low because of liming practices.

SOM was significantly affected by both site and soil depth. The average organic matter content across the three soil depths at the forested site was significantly higher than at the other two sites (3.09%, 2.08%, and 1.78% for the forested, deforested, and cultivated sites, respectively). In most studies, SOM was found to be high in forest soil [15, 34, 35], due to vegetation cover and humus. In our study, the surface soil (0–20 cm) at all sites had the greatest amount of organic matter. The forest site at 0–20 and 20–50 cm had higher amounts of SOM (4.48% and 2.82%, respectively) relative to the same depths at the deforested and cultivated sites (Table 2). At soil depths of 50–80 cm, SOM content was lowest at the cultivated site. Cultivation was associated with significant changes in total nitrogen, and the losses of nitrogen from deforested and cultivated sites appear to be particularly important. Tillage practices and cultivation caused organic matter content to decrease. Patrick and Smith [36] reported that total tree harvesting results in up to three times greater nutrient removal, including nitrogen removal, compared to conventional logging. In addition to losses from biomass removal, when little vegetation is present to take up nutrients at deforested sites, nutrients can be lost by increased soil nutrient mobilization and leaching [37]. The presence of macroaggregates is usually and positively associated with SOM concentration [38]. Clearly, as explained earlier, cultivation breaks up soil aggregates and exposes previously inaccessible organic matter to microbial attack and accelerated decomposition and mineralization of SOM [39].

The conversion of forest and pastureland into cropland deteriorates soil properties, reduces SOM, and changes the distribution and stability of soil aggregates [36, 37]. Relative to SOM in forest and pasture soils, SOM in cultivated soils was reduced by 44% and 48% in the 0–10 cm layer, and by 48% and 50% in the 10–20 cm layer over 12 years, respectively [5]. Hajabbasi et al. [2] reported similar findings, noting that deforestation and subsequent tillage practices resulted in a nearly 50% decrease in SOM at a soil depth of 0–20 cm over 20 years in the central Zagrous Mountains of Iran.

CONCLUSIONS

Each year, hundreds of hectares of land in Turkey are deforested and converted to cropland. We found that some soil properties have been drastically modified by changes in land-use in the village of Unye. Deforestation and subsequent tillage practices changed the distribution and stability of soil aggregates, deteriorated soil properties, and decreased SOM content, SSI, and clay content. Cultivation caused organic matter content to decrease, and reductions in SOM at deforested sites resulted in high DR and ER and low SSI. Thus, deforestation and cultivation increased soil susceptibility to erosion in this region. Because cultivation following deforestation is a common practice in the region, there is a need for a comprehensive soil conservation program to prevent soil erosion problems in susceptible areas.

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