

Effect of different soil conservation methods and planting with four-wing salt bush (*Atriplex canescens*) on soil erosion in a semi-arid region of Turkey

Efecto de diferentes métodos de conservación del suelo y plantación con el arbusto chamiza (*Atriplex canescens*) sobre la erosión del suelo en una región semiárida de Turquía

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SUMMARY

This study was conducted to evaluate whether the four-wing salt bush plant (*Atriplex canescens*) can be used to prevent erosion on the areas with steep slopes with semi-arid conditions by applying different soil conservation methods and planting spaces in a semi-arid region of Turkey. For this purpose, eight treatments with three replications (20 m² plots) were established in the study site to measure amount of runoff and soil loss after precipitation events in 2015 and 2016, where vegetation cover was completely removed by spraying herbicide. Planting holes and terraces were established and half of them were planted with saplings of *Atriplex canescens* with different planting spaces (3 m interval, 0.5 and 1 m distances) to determine if different soil conservation types or combination of them with planting have any impact on soil loss and surface runoff. The results suggested that soil loss and surface runoff in eight treatment plots were higher in 2015 compared to 2016. The highest soil loss was 0.42 Mg ha⁻¹ in the control treatment, while the lowest was 0.11 Mg ha⁻¹ with cultivation with terrace + 50 cm of *A. canescens* in 2015. The total surface runoff was 4.66 mm in the control in 2015 whereas it was 2.33 mm in terracing + planting of *A. canescens* at 50 cm spacing. The combined treatment (terrace with planting of *A. canescens* at 50 cm distance) seems to be the best method to decrease surface runoff and erosion compared to the other treatments employed on the slopes (43 %) in Eskisehir.

Key words: four-wing saltbush, soil conservation, seedling density, erosion control, surface runoff.

RESUMEN

Se evaluó el arbusto *Atriplex canescens* para evitar la erosión en áreas con pendientes pronunciadas con condiciones semiáridas de Turquía, mediante aplicación de diferentes métodos de conservación del suelo y densidades de plantación. Se establecieron ocho tratamientos con tres repeticiones (parcelas de 20 m²) en el sitio de estudio para medir la escorrentía y pérdida de suelo después de los eventos de precipitación en 2015 y 2016, donde la cubierta vegetal se eliminó mediante herbicida. Se establecieron hoyos y terrazas de plantación y la mitad de ellos se plantaron con individuos jóvenes de *A. canescens* con diferentes densidades de plantación (intervalo de 3 m, distancias de 0,5 y 1 m). Los resultados sugirieron que la pérdida de suelo y la escorrentía superficial en las ocho parcelas de tratamiento fueron mayores en 2015 en comparación con 2016. La mayor pérdida de suelo fue de 0,42 Mg ha⁻¹ en el tratamiento de control, mientras que la más baja fue de 0,11 Mg ha⁻¹ con cultivo con terraza + 50 cm de *A. canescens* en 2015. La escorrentía total de la superficie fue de 4,66 mm en el control en 2015, mientras que fue de 2,33 mm en terrazas + plantación de *A. canescens* con un distanciamiento de 50 cm. El tratamiento combinado (terracea con plantación de *A. canescens* a 50 cm de distancia) parece ser el mejor método para disminuir la escorrentía superficial y la erosión en comparación con los otros tratamientos empleados en las pendientes (43 %) en Eskisehir.

Palabras clave: chamiza, conservación del suelo, densidad de plántulas, control de erosión, escorrentía superficial.

INTRODUCTION

Erosion is a natural phenomenon that is characterized by the carry-over of soil due to wind and water in a geological process. However, this process is accelerated by the destruction of plant cover, wrong agricultural practices and improper land use, which is a crucial problem today.

Many countries face erosion danger. Every year 24 billion tons of soils on average are lost due to erosion across the world (Erosion Action Plan in Turkey 2013). Turkey is one of the countries with the maximum scale of erosion. Erosion actively affects 59 % of the agricultural lands, 54 % of the forestlands and 64 % of the rangelands in Turkey (Erosion Action Plan in Turkey 2013).

It is not possible to stop erosion completely. Nevertheless, its impact can be reduced, and speed can be decreased or controlled through certain methods. These methods include the termination of improper agricultural practices, prevention of excessive and early grazing in the rangelands and increased plantation activities in forest lands (Zaimes *et al.* 2019). As a matter of fact, there are several studies conducted in Turkey about this subject (Acar *et al.* 2002, Fidan 2003, Erdem 2005). In addition to these methods, the severity of erosion can be decreased significantly by planting forage crops, which tolerate grazing especially in the arid and semiarid areas where plantation is limited or not possible, can be regenerated quickly, have intensive root structure which enables them to hold the soil tightly and provide organic matter to the soil (Balabanlı *et al.* 2005). However, using appropriate species for the land preparation method and site conditions is an essential factor that affects the success of these efforts. In Turkey, black pine (*Pinus nigra* Arnold.) and cedar (*Cedrus libani* A. Rich.) trees have been mostly used for afforestation in the arid and semi-arid areas for soil conservation (Çalışkan and Boydak 2017), except shallow and litosolic areas, and protected areas where the primary object is to protect existing vegetation cover. The primary method used for forest plantation of the sloped lands in Turkey is to build terraces on the land and plant them with saplings of some tree species. In fact, decreasing slope length by building terraces on the land alone is an important method to decrease the erosion and surface runoff (Chow *et al.* 1999, Shen *et al.* 2010, Liu *et al.* 2013, Li *et al.* 2014, Chen *et al.* 2017).

Atriplex canescens (Pursh.) Nutt. is commonly used for producing roughage, soil reclamation, and combating erosion in problematic areas across the world (Naidu and Harwood 1997, Nefzaoui 1997). Recently, this species has been introduced to Turkey as well. The use of this bush species has yielded positive results as a relatively easy and cheap method applied to improve the soil structure in salty, alkaline, extremely arid, extremely steep areas and mining areas (Houerou 1992). Several studies have been conducted about this plant for many years in the USA, Iran, Australia and many other countries (Glenn and Brown 1998, Koocheki 2000) whereas there are a limited number of studies in Turkey (Erdoğan *et al.* 2013).

Herbaceous and bush species are mainly used for revegetation to prevent erosion in arid and semi-arid areas in Turkey. For example, Güven *et al.* (2015) reported the success of 20 herbaceous and bush species in preventing erosion in the eastern part of Turkey. In that study, soil loss was found to be 19.5 % less in the plots revegetated with bush species and 46 % less in the plots revegetated with herbaceous species compared to the control plot according to the average based on three years of measurements. Soil loss was found to be 33 % less in the parcels planted with herbaceous species than in the parcels planted with bush species. Moreover, Yüksek *et al.* (2018) studied the survival rate of caper bush (*Capparis* spp.) and its importance

to prevent erosion in semiarid areas. They reported that caper bush had a survival rate of 21 % and found that caper bush did not have a significant effect for soil protection from the erosion. Erdoğan *et al.* (2013) conducted a study to determine the forage yield and quality of *Atriplex* spp. growing with different planting spaces and locations. The highest yield and quality were found in Eskisehir-Hamidiye experiment field where the planting space was 2x2 meters, whereas the lowest yield was found in Konya-Karapınar with the lowest precipitation. This study evaluated the forage yield of *Atriplex* spp., and its performance on soil reclamation and erosion prevention by applying two different planting spaces (3x3 m) and (2x2 m) in different regions (Konya/Karapınar, Konya, and Eskisehir/Hamidiye) between 2011 and 2014. The planting space of 2x2 m was found to be more effective compared to 3x3 m in terms of canopy cover that is crucial for erosion control (Sever *et al.* 2014). In regard to the studies conducted across the world, Marques *et al.* (2005), in Spain, found that *Atriplex halimus* L. decreased surface runoff and soil loss from 16.9 to 6.7 ml m⁻² and from 0.16 to 0.02 g m⁻², respectively at a rainfall intensity of 70 mm h⁻¹. Furthermore, Andreu *et al.* (1994) indicated that *Medicago arborea* L. bush was found to be effective to decrease the sediment loss by 47.1 % and surface runoff by 25.7 % compared to bare soil in Spain.

Earlier studies in Turkey mostly focused on yield and adaptation capacity of the *Atriplex* sp. (Erdoğan *et al.* 2013, Sever *et al.* 2014). This study aims at providing complementary contributions to the relevant field since it deals with the effectiveness of *A. canescens* in erosion control studies. The main hypothesis of this study was that *A. canescens* plantation and some terracing combinations are effective tools for erosion and runoff control. In this regard, the objectives of this study are to determine the best conservation method to prevent water erosion in steep slopes in semiarid regions of Turkey and provide guidelines to practitioners and decision makers about the appropriate planting space for *A. canescens* plantations.

METHODS

Study area. This study was conducted on a hillside at an elevation of 899 m and with a slope of 43 % in the Eskisehir Province, Tepebaşı District at the UTM coordinates of 36S 4404586-277659 (figure 1).

The study area is located on northern slope with a soil depth of 70 cm and with limestone and serpentine parent material. The topsoil in the research area consists of sandy clay loam and has a rapid permeability rate (table 1).

The climatic data of Eskisehir meteorology station shows that the annual precipitation is 369 mm while the mean annual temperature is 11 °C in the study area (table 2) (Turkish State Meteorological Service 2018).

Field works. In the study, first the existing vegetation was removed from the area by herbicide spraying in 2014.

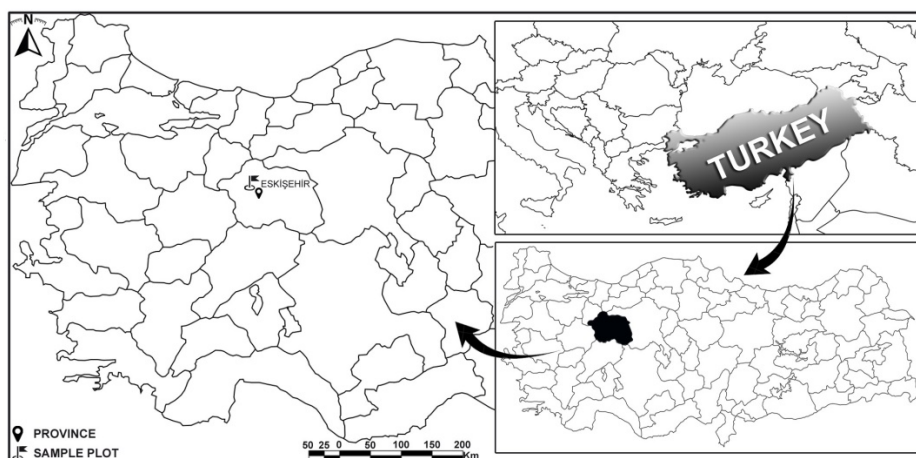


Figure 1. Location of the study site.
 Localización del área de estudio.

Table 1. Topsoil characteristics of the study plots.
 Características del suelo superficial en las parcelas de estudio.

Profile (depth 0-30 cm)	Permeability (mm h ⁻¹)	Volume weight (g cm ⁻³)	Porosity (%)	Max. water holding capacity (%)	Sand (%)	Silt (%)	Clay (%)	Texture
Profile 1	380.0 (Fast)	0.83	68	69.27	45.06	29.58	25.36	Sandy clay loam
Profile 2	255.2 (Fast)	0.84	68	63.59	46.88	25.50	27.62	Sandy clay loam
Profile 3	173.4 (Fast)	0.93	64	64.22	46.69	27.72	25.59	Sandy clay loam

Table 2. Climatic data for the research area.
 Datos climáticos en el área de estudio.

Meteorological variables	Month												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Average temperature (°C)	0.0	1.5	5.2	10.3	15.1	19.1	21.8	21.5	17.3	11.9	6.3	2.1	11.0
Precipitation (mm)	40.3	32.3	37.4	40.8	43.5	32.0	13.0	8.5	15.2	29.5	30.3	46.2	369
Average highest temperature (°C)	4.0	6.4	11.4	17.0	21.8	25.9	29.0	29.3	25.3	19.4	12.4	6.1	17.33
Average lowest temperature (°C)	-3.5	-2.9	-0.4	3.8	7.9	11.3	13.9	13.6	9.5	5.2	1.1	-1.4	4.8

After treatments with terraces and pits, 24 erosion measurement plots (8 treatments x 3 replications with size of 2x10 m) were established and all plots were fenced using polycarbonate materials. Buckets with a cover and with a capacity of 70 liters were placed at the bottom of the plots to collect runoff and sediments in these erosion measurement plots (figure 2).

The experiment was a completely randomized block design with three replications and eight treatments. The treatments were as following:

- 1: Control (without any treatment)
- 2: Digging pits with a spacing of 3 m and distance of 50 cm (no plantation)
- 3: Digging pits with a spacing of 3 m and distance of 100 cm (no plantation)
- 4: Digging pits with a spacing of 3 m and distance of 50 cm + *A. canescens* plantation
- 5: Digging pits with a spacing of 3 m and distance of 100 cm + *A. canescens* plantation
- 6: Terracing at a spacing of 3 m

- 7: Terracing at a spacing of 3 m and planting of *A. canescens* at distance of 50 cm
- 8: Terracing at a spacing of 3 m and planting of *A. canescens* at distance of 100 cm (figure 3).

After each rainfall event, the study site was visited, and the runoff collected from each plot was measured. Afterwards the surface runoff amount was determined;

the amount of sediment load deposited in the buckets was measured. Before the sediment samples were collected, the water and sediments mixture in the buckets was stirred thoroughly and 0.5-liter samples were taken into polyethylene bottles for laboratory analyses. Data collection was carried out between 2015 and 2016. Thus, there were 11 measurements in 2015 and 10 measurements in 2016 that were analyzed.

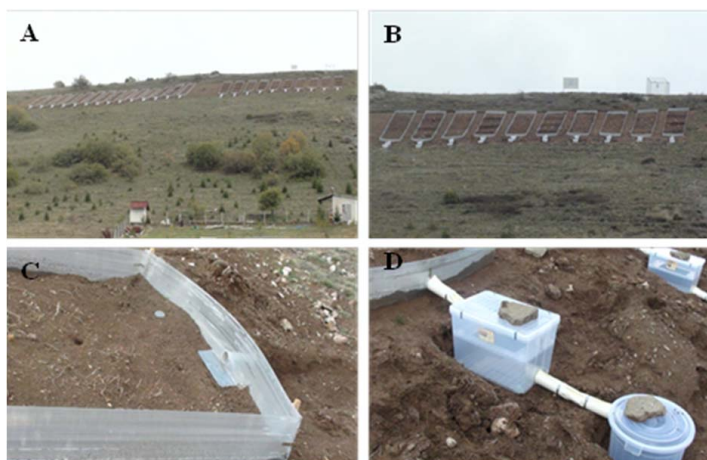


Figure 2. Runoff measurement plots in the research area. A and B: general view of the study area, C: evacuation of runoff and sediments, D: mechanism of reception of runoff and sediments.

Medición de escorrentía en el área de investigación. A y B: vista general del área de estudio, C: evacuación de escorrentía y sedimentos, D: mecanismo de recepción de escorrentía y sedimentos.



Figure 3. Some parts of the treatments in the research area (A: terrace treatments at the beginning of 2015, B: terraces treatments at the end of the 2015 with bushes, C: control plot (right) and dig pits with plants (left) in 2015, D: terrace treatments with bushes and herbaceous plants in 2016).

Parte de los tratamientos en el área de investigación (A: tratamientos de terrazas a principios de 2015, B: tratamientos de terrazas a finales de 2015 con arbustos, C: parcela de control (derecha) y excavaciones de hoyos con planta (izquierda) en 2015, D: tratamientos en terrazas con arbustos y plantas herbáceas en 2016).

Laboratory studies. Samples taken with 0.5-liter polyethylene bottles from each bucket were transported to the laboratory and evaporated at 105 °C. The oven-dried sediment samples were weighed on a balance to calculate their quantity. The amount of sediment carried over from the erosion plot was calculated on the basis of the sediment weight and volume of the runoff accumulated in the buckets. Using this value, the amount of sediment loss from an area of 1 ha in size was calculated considering the size of the study plots. In this way, the impacts of the treatments on soil loss and surface runoff were determined with the use of erosion plots.

Statistical methods. The experiment was a completely randomized block design with eight treatments and three replications. Data were analyzed by ANOVA using SPSS software program and means were compared using Duncan's multiple range test at alpha level of 0.05 ($P < 0.05$) (SPSS v.22.0® 2015).

RESULTS

Sediment quantity. In general, all seven treatments decreased the soil loss in 2015 although not in 2016 compared to control plot. The highest soil loss was found in the control plot with 0.42 Mg ha⁻¹ while the lowest was found in the plot that was cultivated with terrace + 50 cm *A. canescens*

with 0.11 Mg ha⁻¹ in 2015 (table 3). Soil conservation in the form of pits and plantation with *A. canescens* decreased the sediment loss, nevertheless this decrease was not statistically significant. The lowest sediment loss was found in the plot planted with *A. canescens* on terraces. The planting space of 50 to 100 cm for planting *A. canescens* on terraces did not have any significant effect on soil loss.

Sediment loss did not vary significantly across the treatments in 2016. However, sediment quantity decreased significantly compared to the levels in 2015 (table 3).

Runoff. There was significant difference among soil conservation treatments in terms of their effect on the quantity of surface runoff in 2015 while there was not any in 2016. As a matter of fact, the surface runoff was lower in the plots cultivated in the form of terraces (treatments 6, 7 and 8.) compared to the other treatments and control plots, and this difference was statistically significant. The total surface runoff was 4.66 mm in the control plot in 2015 whereas it was 2.33 mm in terracing + planting of *A. canescens* at a spacing of 50 cm (table 4). This means that terracing together with planting *A. canescens* at a distance of 50 cm decreased surface runoff by 50 %.

These differences in surface runoff between the different soil conservation treatments in 2015 were not observed in 2016. Averaging over the years, results of ANOVA revealed that runoff in 2015 was higher than that in 2016

Table 3. Mean annual soil loss under different treatments from study plots.

Pérdida media anual de suelo bajo diferentes tratamientos en las parcelas de estudio.

Years	Treatment plots	Total soil loss (Mg ha ⁻¹)	Precipitation (mm)
2015	Control	0.42 ± 0.13a	402.8
	50 cm P. hole	0.31 ± 0.04a	
	100 cm P. hole	0.31 ± 0.05a	
	50 cm P. hole + <i>A. canescens</i>	0.35 ± 0.08a	
	100 cm P. hole + <i>A. canescens</i>	0.29 ± 0.09a	
	Terrace	0.11 ± 0.01b	
	Terrace+50 cm <i>A. canescens</i>	0.11 ± 0.01b	
	Terrace+100 cm <i>A. canescens</i>	0.13 ± 0.04b	
2016	Control	0.02 ± 0.01b	262.9
	50 cm P. hole	0.02 ± 0.01b	
	100 cm P. hole	0.01 ± 0.00b	
	50 cm P. hole + <i>A. canescens</i>	0.02 ± 0.00b	
	100 cm P. hole + <i>A. canescens</i>	0.02 ± 0.00b	
	Terrace	0.02 ± 0.00b	
	Terrace+50 cm <i>A. canescens</i>	0.02 ± 0.01b	
	Terrace+100 cm <i>A. canescens</i>	0.03 ± 0.00b	

a, b: There are statistical differences at the alpha level = 0.05 among different tillage types in the same column for the same year and between years for the same treatment types (Mean± Standard Error).

Table 4. Mean annual runoff and runoff coefficients from different plots under different treatments.
 Escorrentía media anual y coeficientes de escorrentía de diferentes tratamientos.

Year	Treatment plots	Runoff (mm)	Runoff coefficient (%)	Precipitation (mm)
2015	Control	4.66 ± 0.91a*	1.15 ± 0.22 a	402.8
	50 cm P. Hole	4.40 ± 0.23a	1.09 ± 0.06 a	
	100 cm P. Hole	4.29 ± 0.43a	1.07 ± 0.11 a	
	50 cm P. Hole + <i>A. canescens</i>	4.05 ± 0.91a	1.00 ± 0.23 a	
	100 cm P. Hole + <i>A. canescens</i>	4.01 ± 0.70a	1.00 ± 0.17 a	
	Terrace	2.64 ± 0.48b	0.66 ± 0.12 b	
	Terrace+50 cm <i>A. canescens</i>	2.33 ± 0.31b	0.58 ± 0.08 b	
	Terrace+100 cm <i>A. canescens</i>	2.57 ± 0.57b	0.64 ± 0.14 b	
2016	Control	0.42 ± 0.05c	0.16 ± 0.02 c	262.9
	50 cm P. Hole	0.40 ± 0.08c	0.15 ± 0.03 c	
	100 cm P. Hole	0.34 ± 0.05c	0.13 ± 0.02 c	
	50 cm P. Hole + <i>A. canescens</i>	0.53 ± 0.06c	0.20 ± 0.02 c	
	100 cm P. Hole + <i>A. canescens</i>	0.57 ± 0.15c	0.22 ± 0.06 c	
	Terrace	0.41 ± 0.14c	0.16 ± 0.05 c	
	Terrace+50 cm <i>A. canescens</i>	0.36 ± 0.11c	0.14 ± 0.04 c	
	Terrace+100 cm <i>A. canescens</i>	0.63 ± 0.13c	0.24 ± 0.05 c	

a, b, c: There are statistical differences at the alpha level = 0.05 among different tillage types in the same column for the same year and between the years for the same treatment types (mean± standard error).

and the difference was statistically significant. Surface runoff was 4.66 mm in 2015 in the control plot while it was 0.42 mm in 2016 (table 4).

In terms of the effect of *A. canescens* on the amount of surface runoff there was no significant difference between soil conservation methods (terracing and pit creation) with and without *A. canescens* plantation for both years (table 4). However, terracing was found to decrease possible surface runoff significantly. Surface runoff was found to be less in plots with terraces in both years (table 4).

DISCUSSION

Our findings revealed that terracing and terracing with *A. canescens* had the lowest sediment quantity. Hammad *et al.* (2004) found similar results in a study conducted in Palestine and reported that terrace establishment decreased the sediment delivery from 3.52 to 0.18 Mg ha⁻¹ in the first year and from 5.0 to 0.17 Mg ha⁻¹ in the second year. While some studies suggested that soil tillage intensifies soil erosion (Çepel 1985, Van Oost 2006), pits and terraces decreased soil loss in our study.

Sediment quantity was lower in 2016 for all treatments. This can be explained by the fact that the plots were covered with herbaceous plant species in 2016 and precipitation was lower in 2016 than in 2015. In fact, precipitation

for 2015 was calculated as the sum of 12 months, which was 402.8 mm; whereas it was the sum of eight months in 2016 with 262.9 mm. The total precipitation in the first eight months of 2015 (351.9 mm) was 89 mm higher than that in the first eight months of 2016 (262.9 mm).

In addition to the impact of soil conservation treatments on the reduction of erosion in 2015, it was observed that natural herbaceous vegetation was more effective in reduction of erosion than were soil conservation treatments in 2016. As soil surface was covered with natural herbaceous vegetation in 2016, the decrease in soil erosion could be attributed to the vegetation cover. As a matter of fact, while the surface covered with vegetation was 30 % on average in 2015, this ratio was measured as 80 % in 2016. Loch (2000) reported that sediment quantity could be reduced from 30-35 Mg ha⁻¹ to 0.5 Mg ha⁻¹ when the rate of herbaceous vegetation cover was increased from 0 % to 47 %. In this study, soil tillage was found to be effective to decrease erosion in the first year. Daşdemir *et al.* (1996) reported that the types of terraces were effective in erosion control and thus created an environment for vegetation. Erdem (2005) stated that ploughed pits vertical to the slope direction at different depths on agricultural fields decreased soil loss as the pit depth increased.

The most prominent result of this study in terms of surface runoff was that terracing + planting of *A. canescens* at

a distance of 50 cm was the most efficient method in the first year. Hammad *et al.* (2004) also reported that terracing decreased surface runoff by 59 % on average. Uslu (1971) reported that the highest surface runoff was found on the bare parcels depending on precipitation while the lowest surface runoff was found to be on the bush-covered parcels. Moreover, Aydemir (1973) reported that vegetative plantations for the reclamation of the basin around Eymir Lake in Ankara were effective in decreasing surface runoff.

Runoff was not different among treatments in the second year mostly because of the lesser precipitation and increased vegetation cover. Kinetic energy of raindrops as a function of amount and intensity of precipitation is one of the most effective factors on runoff and soil erosion (Ran *et al.* 2012). Güven *et al.* (2015) reported 34 % lesser runoff as a result of growth performance of herbs and shrubs and their vegetation cover on the soil surface. Furthermore, the comparative study between the bush and herbaceous plants covered plots revealed that herbaceous vegetation was better in preventing water loss than the bush-covered plots. A similar study conducted in Australia (Loch 2000) showed that as the amount of herbaceous vegetation on the soil increased, both surface runoff and erosion decreased substantially.

Our findings were consistent with those of the studies reporting that operations performed parallel to the slope (tillage, furrow, terrace, plant) were effective in decreasing surface runoff (Aydemir 1973, Daşdemir *et al.* 1996, Erdem 2005, Shen *et al.* 2010, Liu *et al.* 2013, Li *et al.* 2014, Chen *et al.* 2017).

High permeability and porosity in the topsoil, as well as low precipitation, are often referred as the reason of low surface runoff as it is in all treatments in the current study. Analyses of the soil samples collected from the study area revealed that soil permeability was 269.3 mm h⁻¹ (fast) on average and the mean porosity was 66.8 % (table 1).

CONCLUSIONS

In this study, the effect of soil conservation methods and planting space of *A. canescens* on surface runoff and sediment loss was investigated in a semi-arid area on steep slopes in Turkey. Terraces and planting of *A. canescens* had an impact in preventing sediment loss and surface runoff. Surface runoff and sediment loss decreased as the planting space got smaller. We understood from these results that the planting intervals used in this study are not adequate. Hence, further studies with closer intervals are needed to explore the effect of *A. canescens* or similar bushes on surface runoff and sediment loss.

Coverage of the area with herbaceous vegetation and substantial reduction in erosion in the second year due to this vegetation makes it necessary to study the effect of terraces and planting of different herbaceous species together. It can be concluded that terracing and planting of herbaceous species were more effective than planting of

bush species for the quick control of soil loss. Introducing bush or tree species in the following years can be suggested for long term results in preventing erosion. These rehabilitation methods can be used as an effective measure to prevent erosion in similar sites. *Atriplex canescens* saplings have a high survival rate, a good adaptation capability and tolerance to drought and cold weather conditions. Similarly, they remain green in semiarid areas in dry summer periods. Therefore, they can be used as an alternative forage crop in rangelands for domestic and wildlife animals.

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