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ORIGINAL ARTICLE

Ability of green cover from sainfoin (*Onobrychis viciifolia* Scop.) and dog rose (*Rosa canina* L.) to control erosion and improve soil organic carbon and nitrogen stocks in terraces of Northwest Turkey

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Abstract

The main aim of this study was to evaluate the impact of green cover and afforestation on soil properties, erosion susceptibility, as well as soil organic carbon (SOC) and soil total nitrogen (STN) contents and stock capacities. Mineral soil samples from two soil depths (0–10 cm and 10–20 cm) were obtained from a bare soil plot (BSP), a young forest plot (7-year-old juvenile cover; YFP), a mature forest plot (MFP) used as a reference control, a young forest plot with sainfoin green cover (YFP + S), and a young forest plot with dog rose green cover (YFP + R). The soil samples were analyzed for pH, water holding capacity (WHC), soil texture, dispersion ratio, bulk density, SOC, STN, and soil extractable P and K. Soil bulk density, soil volume, and the SOC and STN were used to calculate the mean SOC and STN stocks. Results showed that afforestation and green cover significantly influenced the chemical and physical properties of the soil, reduced its dispersion ratio, and increased its SOC and STN stock capacities ($P < 0.05$). The mean SOC stock was highest for MFP (39.7 t C ha^{-1}), followed by YFP + R (37.1 t C ha^{-1}), YFP + S (35.7 t C ha^{-1}), YFP (22.1 t C ha^{-1}), and BSP (10.9 t C ha^{-1}). However, the mean STN stock was highest for YFP + S (2.40 t N ha^{-1}), followed by MFP (2.25 t N ha^{-1}), YFP + R (2.08 t N ha^{-1}), YFP (1.88 t N ha^{-1}), and BSP (0.55 t N ha^{-1}). These results indicate that with proper care and management, natural or artificial leguminous and shrub species can provide year-round soil protection and minimize soil erosion in black pine plantation terraces. Growing these species could enhance soil productivity by increasing soil organic matter, improving the soil structure, and increasing the water holding capacity and nutrient retention of the soil.

Keywords Green cover · Dog rose · Sainfoin · Erosion control terraces · Turkey

Introduction

For the last two centuries, one of the main environmental concerns around the world has been desertification (Kosmas et al. 2000; Carvalho-Santos et al. 2016). Low levels of vegetative cover are found in arid and semiarid regions in particular, due to their dry climates (Díaz et al. 1994). This reduced vegetation cover means that the soil in these regions is relatively unprotected from the damage caused by wind or rain (Guerra and Pinto-Correia 2016), which greatly accelerates soil erosion and structural breakdown. Therefore, many field strategies and techniques have been devised to suppress this damage caused by wind and water erosion to the soil in semiarid and arid regions. Among these techniques, the most popular are terracing, the use of trenches, silt traps, and reforestation. However, the relationship between the amount of vegetative cover and soil erosion has not received much attention from researchers. Ranney et al. (1987) emphasized that there is insufficient information on erosion in a woody biomass setting. Green et al. (1996) showed that, without green cover (i.e., in a weed-free environment), sediment loss from sweetgum tree plots increased over time. Those authors stated that erosion would slow down with increasing crown closure during subsequent years of growth. In recent years, it has been realized that the use of green cover to alleviate erosion problems and reduce runoff and soil loss yields better

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results than implementing young tree plantations (Zuazo et al. 2011).

A number of authors (e.g., Zuazo and Pleguezuelo 2008; Rodrigues et al. 2015) have noted that green cover intercepts rainfall (thus protecting the soil surface from rainfall-induced damage) and reduces runoff in the short term, while it also exerts a long-term influence on water and sediment fluxes by increasing soil aggregate stability and cohesion and improving water infiltration. In arid and semiarid areas, new terraces that are constructed to control erosion are characterized by unfavorable conditions (sparse vegetation, a lack of water or waterlogged conditions, and poor soil) for establishing vegetation due to the microclimate of the area and the eroded condition of the soils (Afrasinei et al. 2017). The use of green cover in these terraces can allow the generation of ecosystems that are capable of providing various services. When soil is eroded, soil organic matter, including carbon and essential nutrients such as P, N, and K, is also transported out of the soil (Martínez-Mena et al. 2002). In addition to erosion control, green cover ecosystems also provide other important ecosystem services, such as binding C and mitigating climate change (Lobb et al. 2002). In general, researchers are in agreement that land-use/land-cover changes can lead to significant decreases in soil organic carbon (SOC) and soil total nitrogen (STN) stock capacities due to disturbance and cultivation (Edmondson et al. 2014). A number of studies have also focused on the effects of afforestation and green cover vegetation on C and N stock capacities and nutrient contents (Rodríguez et al. 2009a; Premrov et al. 2012; Cotler et al. 2013; Song et al. 2016). Those studies found that establishing green cover on terraces can help to accumulate atmospheric C and N in soil (Rodrigues et al. 2013; Ravindran and Yang 2015; Junqiang et al. 2016; Kaibo et al. 2016), which is important given that atmospheric C and N are the most significant C and N sinks in terrestrial ecosystems.

Soil erosion is the main environmental problem in many regions of Turkey, and it is also considered to be the most serious environmental issue in Europe (De Luis et al. 2010). In the last few decades, soil fertility in some regions of Turkey has gradually deteriorated due to excessive cultivation and overgrazing. This has resulted in increased soil compaction and erosion, leading to soil degradation and land abandonment. Using the land intensively has increased tree mortality and reduced natural tree regeneration on these sites. It has been estimated that 59% of the agricultural area, 54% of the forestland, and 64% of the rangeland in Turkey are at risk of erosion (Günal et al. 2015). The most widely used technique for preventing soil surface erosion in Turkey is terracing, in which young trees are planted with spaces between them on terraces (Zuazo and Pleguezuelo 2008). However, the canopies of young trees can only protect a small proportion of the soil surface from damage caused by wind and raindrops. Therefore, an understanding of how the use of green cover on terraces affects soil properties, erosion susceptibility, and SOC and STN stocks is required to devise better strategies for reducing soil erosion and mitigating climate change in Turkey. However, this topic has not received much attention, and the use of green cover is rarely considered in Turkey. Also, only a few studies have investigated how tree species, green cover species, and land-use/land-cover changes are related to SOC and STN stock capacities in Turkey (Mısır and Mısır 2013; Sariyildiz et al. 2016).

Several grass species (e.g., *Lolium perenne*, *Elymus glaucus*, and *Chrysopogon zizanioides*) and shrub species (e.g., *Medicago arborea*, *Atriplex nummularia*, and *Psoralea bituminosa*) have been tested and used in many countries to prevent water erosion and soil losses, depending on their availability and cost (Andreu et al. 1998). Canadell et al. (1996) have stated that shrubs generally have deeper roots than leguminous plants. Dog rose (*Rosa canina* L.)—a hermaphroditic shrub—can be seen growing individually or in groups throughout Turkey, and is used in landscape planning and erosion control studies (Ilisulu 1992). Sainfoin (*Onobrychis viciifolia* Scop.) grows in warm-temperate and dryland areas of Europe, Asia, and western North America (Frame 2005). It is a perennial forage legume that tolerates high levels of active lime in the soil (De Falco et al. 2000) as well as low phosphorus levels. Cash and Ditterline (1996) noted that it has a low nitrogen fixation capacity compared to major perennial legumes, but that it has a well-developed root system which increases its capacity to tolerate soil moisture deficiency.

The objectives of the present study were to (i) demonstrate the efficiency of sainfoin (*Onobrychis viciifolia* Scop.) and dog rose (*Rosa canina* L.) at reducing soil erosion and improving soil properties, and (ii) compare the soil organic matter, soil organic carbon, and total nitrogen contents of soils under sainfoin and dog rose, adjacent bare soil, newly established terraces with cover from 7-year-old juvenile trees, and mature forest sites to determine how green cover affects soil C and N storage.

Materials and methods

Study areas

This study was carried out within the borders of Kastamonu Province, Northwest Turkey (41°23′19″N, 33°46′57″E; Fig. 1). The mean altitude of the study site is 450 m a.s.l. and it has a northeasterly aspect. Climate data for the period 1960–2014 (from the meteorology station in Kastamonu; see Table 1) indicate that precipitation averages 497.3 mm year^{-1} in the study area. The climate in this area is characterized by semiarid summers and cold winters.

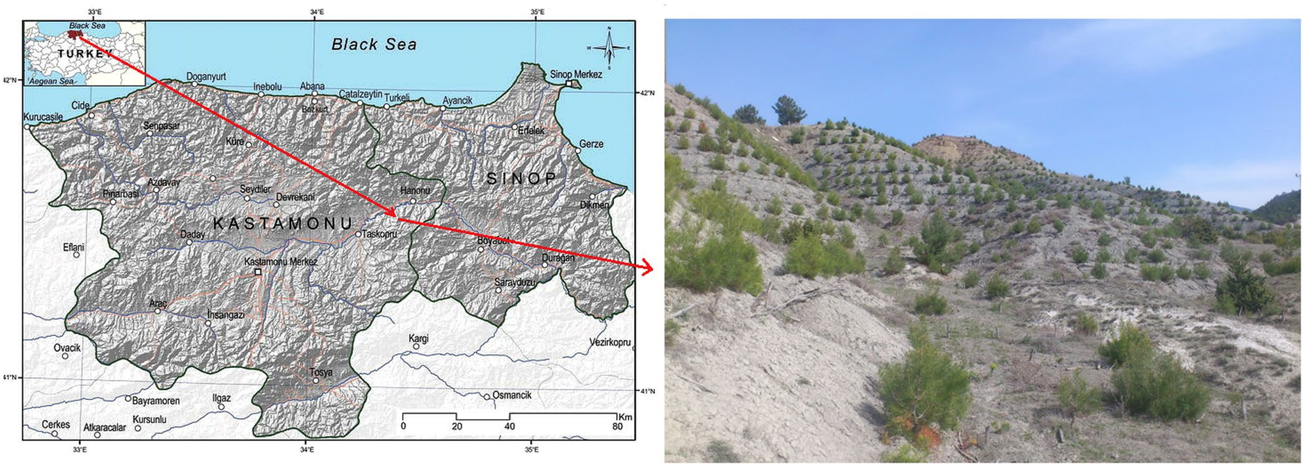

Fig. 1 Location of the study area in northwest Turkey

Table 1 Thornthwaite balance for the study area (climate data cover the period 1960–2014)

	Month												mm year^{-1}
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Air temperature (°C)	−0.9	0.7	4.4	9.5	14.0	17.5	20.2	19.8	15.5	10.5	5.0	0.9	9.78
Heat index	0	0.05	0.82	2.64	4.75	6.66	8.47	8.03	5.55	3.07	1.00	0.07	41.11
Unadjusted PE (mm month^{-1})	0	1.9	15.9	38.8	60.8	78.7	94.5	90.8	68.4	43.6	18.5	2.5	
Potential evapotranspiration (PE)													
Adjustment factor	0	0.83	1.03	1.11	1.25	1.26	1.27	1.19	1.04	0.96	0.82	0.80	
PE (mm month^{-1})	0	1.6	16.4	42.9	74.7	97.3	118.5	106.5	70.9	42.1	15.6	2.1	588.6
Precipitation (mm month^{-1})	31.3	28.3	35.8	56.0	69.4	73.4	34.5	32.4	33.4	37.3	29.0	36.5	497.3
Change in soil water storage (mm month^{-1})	31.3	20.9	0	0	−5.3	−23.9	−70.8	0	0	0	13.4	34.4	
Storage (mm month^{-1})	79.1	100	100	100	94.7	70.8	0	0	0	0	13.4	47.8	
Actual evapotranspiration (mm month^{-1})	0	1.6	16.4	42.9	74.7	97.3	105.3	32.4	33.4	37.3	15.6	2.1	459
Water deficit (mm month^{-1})	0	0	0	0	0	0	13.2	74.1	37.5	4.8	0	0	129.6
Water surplus (mm month^{-1})	0	5.8	19.4	13.1	0	0	0	0	0	0	0	0	38.3
Runoff (mm month^{-1})	0	2.9	11.2	12.2	6.1	3.1	1.5	0.7	0.3	0.2	0.1	0	38.3
Soil moisture storage (mm month^{-1})	0	16.7	1.2	0.3	−0.07	−0.2	−0.7	−0.7	−0.5	−0.1	0.8	16.4	

The mean monthly temperature varies from 20 to −0.9 °C, and the mean annual temperature is 9.8 °C. The study area has basic and ultrabasic parent material of various sizes. The underlying bedrock within the study area is quartzite-quartz schist, andesine, sandstone-mudstone, and limestone (Dengiz et al. 2019). The soil type is Calcisol (calcareous brown earth) (Kapur et al. 2018). In terms of land use and vegetation, the study area was mostly covered with forest, arable land, and pasture. The Kastamonu Regional Forest Directorate uses the terracing system to control soil erosion; it has been intensively planting black pine (*Pinus nigra* subsp. *caramanica*) on the terraces since 2008 (Fig. 1). The Regional Forest Directorate also planted sainfoin (*Onobrychis viciifolia* Scop.) in the study area in 2012 in order to monitor soil loss and runoff from the black pine terraces, and the shrub dog rose (*Rosa canina* L.) has been allowed to grow on some of the terraces.

Soil samples were also taken from study plots with various characteristics (Fig. 2) in 2014 and 2015:

- A young forest plot with 7-year-old juvenile cover (YFP) (Fig. 2a)
- A young forest plot with naturally grown (i.e., no planting date) dog rose (YFP + R) (Fig. 2b)
- A young forest plot with artificially planted (2012) sainfoin green cover (YFP + S) (Fig. 2c)
- A mature forest plot (over 30 years old) used as a reference control plot (MFP) (Fig. 2d)
- A plot that has had bare soil since the year 1990 (BSP) (Fig. 2e).

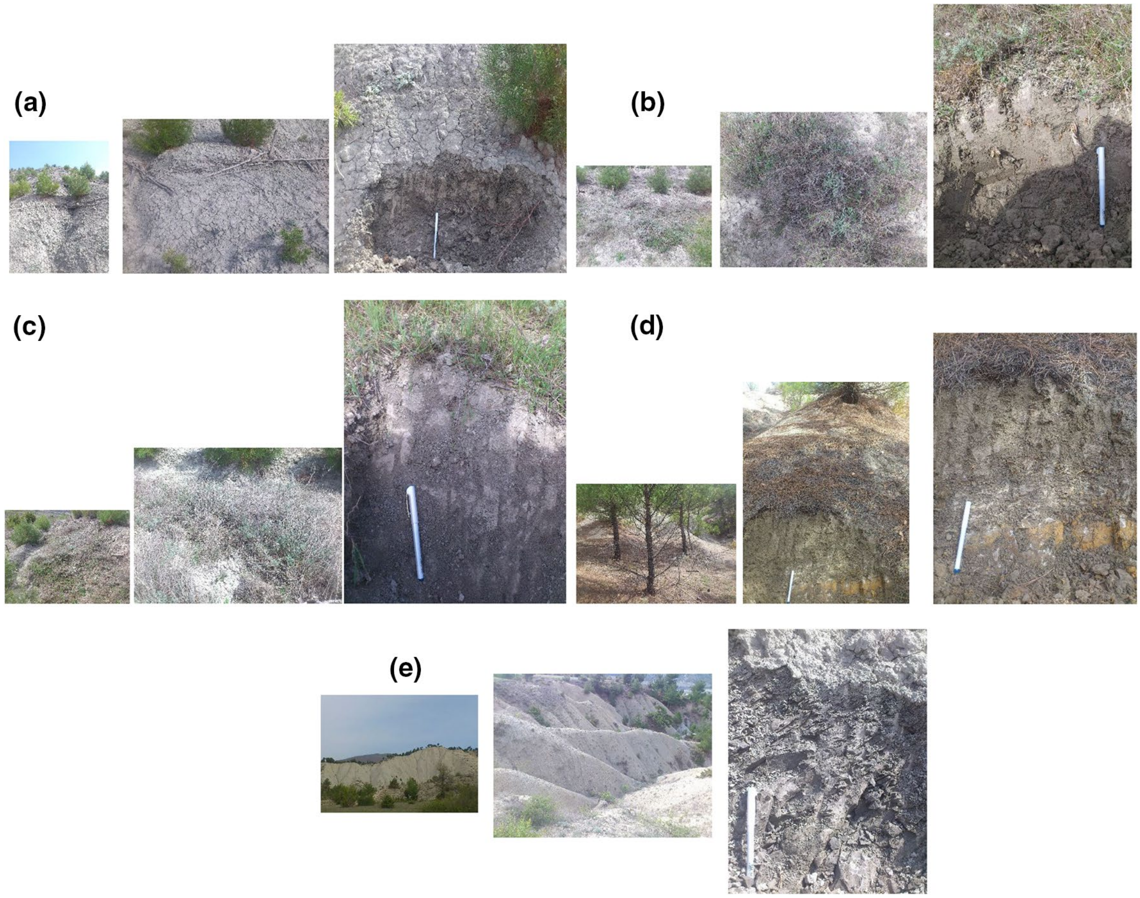

Fig. 2 Overview of the study sites: **a** young forest plot with 7-year-old juvenile cover (YFP), **b** young forest plot with naturally grown dog rose (YFP + R), **c** young forest plot with artificially planted sainfoin (YFP + S), **d** mature forest plot used as a reference control plot (MFP), and **e** bare soil plot (BSP)

Soil samples were taken from exactly the same locations in each plot in the autumns of 2014 and 2015. Three subplots adjacent to each other (replicates, 20 m × 20 m = 400 m^2) were chosen for each plot, and the soil was sampled in each subplot. Three soil pits were dug at the top, the middle, and the bottom of each subplot. Soil samples were taken from the soil to a depth of 20 cm. A soil core sampling device (inner diameter: 5 cm) was used to obtain the soil samples. Mineral soil sample cores were used to get soil samples from two different soil depths (0–10 cm and 10–20 cm). The samples obtained were passed through a 2-mm soil siever to get rid of stones and gravel. The total number of samples taken from the two soil depths was 60 [5 study plots × 2 soil depths × 2 sampling times (2014 and 2015) × 3 subplots = 60 soil cores]. The soil samples were subsequently analyzed for pH, soil texture, bulk density, dispersion ratio, water holding capacity, SOC, STN, and P and K concentrations. In addition, the SOC and STN stock capacities were calculated. Differences between the soil properties and SOC and STN stocks at the two soil depths (0–10 cm and 10–20 cm) were evaluated.

Soil analysis

Soil pH was determined using a combination glass electrode in H_2O (soil:solution 1:2.5) (Gülçur 1974). The Bouyoucos hydrometer method (Gülçür 1974, modified from Bouyoucos 1962) was used to determine soil texture. Samples were pretreated with 10% NH_4OH to remove organic matter, and NaHMP, i.e., $(NaPO_3)_6$, was used as a dispersal agent to minimize foaming (Gülçür 1974). The water holding capacity of the soil was determined as the amount of water that could be held by the soil sample compared to the dry weight of the sample (Verdonck and Gabriels 1992). Bulk density was determined as the ratio of the dry weight of the soil to the ring volume. Prior to analyses of organic C, the soil samples were treated with 2 M HCl to remove inorganic C (Allen 1989). The Leco dry combustion technique utilizing an elemental analyzer was employed to determine the soil organic C and total N. Soil extractable P and K were extracted using a solution containing 1 N ammonium acetate (CH_3COONH_4), 0.005 N acetic acid (CH_3COOH), and 0.015 N ammonium fluoride (NH_4F). The PO_4-P concentration was determined colorimetrically using an autoanalyzer, whereas the K concentration was determined using a flame photometer (Ashworth and Mrazek 1995). The dispersion ratio of the soil was determined using the method of Middleton (1930). This ratio was obtained by dividing the amount of silt plus clay that was easily suspended after shaking the soil in pure water by the total quantity of silt plus clay that was present. The dispersion ratio was calculated as follows:

$$\text{Dispersion ratio} = D/T,$$

where D is the amount of silt and clay that is dispersed when 1 kg of oven-dried soil is added to a liter of distilled water and shaken for 20 min, and T is the total silt and clay in the soil as determined by the standard sediment method with the soil in a nondispersed state. A dispersion ratio of less than 15 was considered to indicate nonerosive soil, while a ratio of more than 15 was considered to indicate erosive soil (Middleton 1930).

Total soil organic C and TN stocks were calculated using the following formula:

$$\text{Organic C or N stock(t/ha)} = \text{organic C or N content} \times \text{ds} \times \text{th},$$

where ds is the soil bulk density (t m^{-3}), th is the thickness of the soil layer (m), and t/ha is the abbreviation for tonnes per hectare (Lee et al. 2009).

Data analysis

The effects of the green cover and the soil depth on soil properties, the dispersion ratio, as well as soil organic carbon and total nitrogen and their stock capacities were analyzed via two-way ANOVA (analysis of variance) using the software SPSS (version 11 for Windows). After performing the ANOVA, multiple comparisons of soil properties, dispersion ratios, soil organic carbon and total nitrogen and their stock capacities as well as interactions of green cover with soil depth for each green cover type were carried out using Tukey's honestly significant difference (HSD) test ($\alpha = 0.05$).

Results

Effects of green cover and soil depth on soil texture and the dispersion ratio

Results for the soil texture and dispersion ratios of the soils from the five experimental plots are given in Table 2. The individual effects of green cover on soil sand, silt, and clay contents and the dispersion ratio are listed in Table 3. The main effects of green cover on soil texture and the dispersion ratio were all significant at the 95% level ($\alpha = 0.05$), while the main effects of soil depth were only significant for clay content and dispersion ratio (Table 3). Soil clay content decreased with increasing soil depth while dispersion ratio increased with increasing soil depth (Table 2).

For the 0–10 cm soil layer, MFP had the highest clay content (49 ± 0.56%), followed by YFP + S (46 ± 1.2%), YFP + R (44 ± 0.78%), YFP (37 ± 1.01%), and BSP (30 ± 1.5%). Silt content was highest for MFP (37 ± 0.5%), followed by YFP + R (31 ± 0.9%), YFP (29 ± 0.4%), YFP + S (26 ± 0.3%), and BSP (24 ± 0.7%). However, soil sand content decreased in the following plot order: BSP (46 ± 0.2%) > YFP (34 ± 0.2%) > YFP + S (28 ± 0.8%) > YFP + R (25 ± 0.3%) > MFP (14%). The dispersion ratio was highest for MFP (29), followed by YFP (25), YFP + S (22), YFP + R (21), and MFP (19).

For the 10–20 cm soil layer, the soil clay and silt contents decreased in the following plot order: YFP + R > YFP + S > MFP > YFP > BSP, while the soil sand content decreased in the following order: BSP > YFP > MFP > YFP + S > YFP + R (Table 2). The dispersion ratio was also highest for MFP (40), followed by YFP (35), YFP + S (28), MFP (26), and YFP + R (23).

Table 2 Differences in soil texture and dispersion ratio between the five study plots at soil depths of 0–10 cm and 10–20 cm

Plot	Soil depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture type	Dispersion ratio	Erosion sensitivity
BSP	0–10	30 ± 1.5	24 ± 0.7	46 ± 0.2	Clayey	29	Moderately sensitive
YFP		37 ± 1.01	29 ± 0.4	34 ± 0.2	Clayey	25	Moderately sensitive
MFP		49 ± 0.56	37 ± 0.5	14 ± 0.4	Clayey	19	Sensitive
YFP + R		44 ± 0.78	31 ± 0.9	25 ± 0.3	Clayey	21	Sensitive
YFP + S		46 ± 1.2	26 ± 0.3	28 ± 0.8	Clayey	22	Sensitive
BSP	10–20	31 ± 0.6	24 ± 0.8	45 ± 0.7	Clay-loam	40	Highly sensitive
YFP		37 ± 1.3	25 ± 0.7	38 ± 0.7	Clayey	35	Highly sensitive
MFP		38 ± 1.4	26 ± 0.7	36 ± 0.5	Clayey	26	Moderately sensitive
YFP + R		43 ± 0.9	37 ± 0.9	20 ± 0.2	Clayey	23	Sensitive
YFP + S		41 ± 1.6	30 ± 0.5	29 ± 0.8	Clayey	28	Moderately sensitive

Table 3 ANOVA of soil texture and dispersion ratio

Soil parameter	Source	SS	*df*	MS	*F*	Eta squared
Sand content (%)	Plant cover	35,638.533	1	35,638.533	1572.288**	0.591
	Soil depth	654.467	4	163.617	7.218	0.115
	Plant cover × Soil depth	58.800	1	58.800	2.594*	0.457
	Error	380.867	4	95.217	4.201	
Silt content (%)	Plant cover	171.467	4	42.867	4.175*	0.455
	Soil depth	3.333	1	3.333	0.325	0.016
	Plant cover × Soil depth	153.333	4	38.333	3.734*	0.428
	Error	205.333	20	10.267		
Clay content (%)	Plant cover	155.867	4	38.967	9.133***	0.646
	Soil depth	56.033	1	56.033	13.133**	0.396
	Plant cover × Soil depth	160.133	4	40.033	9.383***	0.652
	Error	85.333	20	4.267		
Dispersion ratio	Plant cover	780.467	4	195.117	146.337***	0.967
	Soil depth	360.533	1	360.533	270.400***	0.931
	Plant cover × Soil depth	73.800	4	18.450	13.837***	0.735
	Error	26.667	20	1.333		

SS sum of squares, *df* degrees of freedom, *MS* mean squares

Asterisks indicate the level of significance: *$P<0.05$; **$P<0.01$; ***$P<0.001$

All of these soil parameters had a significant ($P<0.05$ for sand and silt contents, $P<0.001$ for the clay content and dispersion ratio) green cover × soil depth interaction, indicating that these soil parameters showed different trends depending on the soil depth under the green cover (Table 3).

Effects of green cover and soil depth on soil chemical properties

The results for some chemical properties (soil pH, WHC, and soil extractable P and K) of the soils from the five study sites are shown in Table 4. The individual effects of green cover on soil pH, WHC, and soil extractable P and K are listed in Table 5. The main effects of green cover on these soil properties were all significant at the 95% level ($\alpha=0.05$), while the main effects of soil depth were only significant for WHC and for soil extractable P and K (Table 5). Water holding capacity and soil extractable K decreased with increasing soil depth (Table 4).

For the 0–10 cm soil layer, soil pH increased in the following plot order: YFP + R (7.01 ± 0.22) < MFP (7.13 ± 0.11) < YFP + S (7.55 ± 0.32) < YFP (8.04 ± 0.21) < BSP (8.25 ± 0.13), while WHC decreased in the following order: YFP + R (70 ± 3%) > YFP + S (63 ± 1%) > MFP (58 ± 2%) > YFP (55 ± 3%) > BSP (53 ± 2%). Soil bulk density was highest for BSP (1.28 ± 0.06 g cm^{-3}), followed by YFP (1.19 ± 0.02 g cm^{-3}), MFP (1.12 ± 0.01 g cm^{-3}), YFP + S

Table 4 Differences in some soil properties between the five study plots at soil depths of 0–10 cm and 10–20 cm

Plot	Soil depth (cm)	Bulk density (g cm^{-3})	pH (H_2O)	WHC (%)	Soil extractable P (kg ha^{-1})	Soil extractable K (kg ha^{-1})
BSP	0–10	1.28 ± 0.06	8.25 ± 0.13	53 ± 2	0.151 ± 0.013	5.78 ± 1.11
YFP		1.19 ± 0.02	8.04 ± 0.21	55 ± 3	0.174 ± 0.021	6.71 ± 0.45
MFP		1.12 ± 0.01	7.13 ± 0.11	58 ± 2	0.333 ± 0.011	7.86 ± 0.98
YFP + R		0.93 ± 0.05	7.01 ± 0.22	70 ± 3	0.372 ± 0.033	12.2 ± 1.32
YFP + S		0.99 ± 0.02	7.55 ± 0.32	63 ± 1	0.305 ± 0.041	9.23 ± 0.55
BSP	10–20	1.39 ± 0.03	8.21 ± 0.09	52 ± 2	0.128 ± 0.022	6.59 ± 0.32
YFP		1.24 ± 0.06	8.07 ± 0.15	54 ± 1	0.199 ± 0.011	6.50 ± 1.74
MFP		1.15 ± 0.06	7.06 ± 0.17	58 ± 2	0.217 ± 0.043	7.89 ± 0.34
YFP + R		1.02 ± 0.04	7.00 ± 0.11	67 ± 2	0.302 ± 0.053	10.8 ± 1.22
YFP + S		1.05 ± 0.04	7.12 ± 0.16	60 ± 3	0.352 ± 0.026	11.7 ± 1.03

Table 5 ANOVA of soil pH, soil bulk density, WHC, and soil extractable P and K

Soil parameter	Source	SS	*df*	MS	*F*	Eta squared
pH	Plant cover	5.072	4	1.268	608.636***	0.992
	Soil depth	0.001	1	0.001	0.518	0.025
	Plant cover × Soil depth	0.051	4	0.013	6.090**	0.549
	Error	0.042	20	0.002		
WHC	Plant cover	821.467	4	205.367	74.229***	0.937
	Soil depth	45.633	1	45.633	16.494**	0.452
	Plant cover × Soil depth	16.533	4	4.133	1.494	0.230
	Error	55.333	20	2.767		
Bulk density	Plant cover	0.326	4	0.082	153.978***	0.969
	Soil depth	0.106	1	0.106	199.270***	0.909
	Plant cover × Soil depth	0.018	4	0.004	8.406**	0.627
	Error	0.011	20	0.001		
Extractable P	Plant cover	0.193	4	0.048	21.425***	0.422
	Soil depth	0.007	1	0.007	0.204	0.010
	Plant cover × Soil depth	0.153	4	0.038	1.127	0.184
	Error	0.678	20	0.034		
Extractable K	Plant cover	196.722	4	49.181	788.867***	0.994
	Soil depth	4.234	1	4.234	67.910***	0.772
	Plant cover × Soil depth	3.437	4	0.859	13.782*	0.734
	Error	1.247	20	0.062		

SS sum of squares, *df* degrees of freedom, *MS* mean squares

Asterisks indicate the level of significance: *$P<0.05$; **$P<0.01$; ***$P<0.001$

(0.99 ± 0.02 g cm^{-3}), and YFP + R (0.93 ± 0.05 g cm^{-3}). Soil extractable P and K decreased in the same order of plots as for WHC: YFP + R (0.372 ± 0.033 and 12.2 ± 1.32 kg ha^{-1}, respectively) > YFP + S (0.305 ± 0.041 and 9.23 ± 0.55 kg ha^{-1}, respectively) > MFP (0.333 ± 0.011 and 7.86 ± 0.98 kg ha^{-1}, respectively) > YFP (0.174 ± 0.021 and 6.71 ± 0.45 kg ha^{-1}, respectively) > BSP (0.151 ± 0.013 and 5.78 ± 1.11 kg ha^{-1}, respectively).

For the 10–20 cm soil layer, just as for the top soil layer, the soil pH increased in the following plot order: YFP + R < MFP < YFP + S < YFP < BSP, while WHC decreased in the following order: YFP + R > YFP + S > MFP > YFP > BSP. The small differences in soil pH between the two soil depths may be attributed to relatively low levels of precipitation, meaning that there was little leaching through the soil, or the presence of a calcareous soil parent material, leading to similar pH values at the two soil depths. The soil bulk density increased in the same plot order as seen for the top soil layer, while soil extractable P and K were highest for YFP + S, followed by YFP + R, MFP, YFP, and BSP (Table 4).

Soil pH and soil extractable K presented a significant ($P<0.05$) green cover × soil depth interaction, indicating that these soil chemical parameters show different trends depending on the soil depth (Table 5).

Effects of green cover and soil depth on the SOC and TN and their stocks

Results for the SOC and TN and their stocks in the soils from the five experimental areas are given in Table 6. The individual effects of green cover on soil organic carbon, total nitrogen, and their stock capacities are listed in Table 7. The main effects of green cover on soil organic carbon, total nitrogen, and their stock capacities were all significant at the 95% level ($\alpha=0.05$), while the main effects of soil depth on these parameters were also all significant with the exception of soil organic carbon stock capacity (Table 7). Soil organic carbon, total nitrogen, and the stock capacity of total nitrogen decreased with soil depth (Table 6).

For the 0–10 cm soil layer, MFP presented the highest SOC (1.76 ± 0.16%), followed by YFP + R (1.69 ± 0.20%), YFP + S (1.55 ± 0.25%), YFP (1.33 ± 0.10%), and BSP (0.46 ± 0.10%), while YFP + S had the highest STN (0.217 ± 0.011%), followed by YFP + R (0.119 ± 0.003%), MFP (0.102 ± 0.001%), YFP (0.099 ± 0.011%), and BSP (0.0242 ± 0.0023%). Soil organic carbon stock capacity decreased in the following plot order: MFP (19.7 ± 1.77 t C ha^{-1}) > YFP + S (18.4 ± 2.98 t C ha^{-1}) > YFP + R (15.7 ± 1.90 t C ha^{-1}) > YFP (11.8 ± 0.92 t C ha^{-1}) > BSP (5.45 ± 1.23 t C ha^{-1}), while STN stock capacity decreased

Table 6 Mean soil organic carbon (%), total nitrogen (%), organic carbon stock capacity (t C ha^{-1}), and total nitrogen stock capacity (t N ha^{-1}) at the two soil depths in the five plots

Plot	Depth (cm)	Soil organic carbon (SOC) (%)	Soil total nitrogen (STN) (%)	STN stock capacity (t N ha^{-1})	SOC stock capacity (t C ha^{-1})
BSP	0–10	0.46 ± 0.10	0.0242 ± 0.0023	0.285 ± 0.03	5.45 ± 1.23
	10–20	0.42 ± 0.13	0.0201 ± 0.0013	0.260 ± 0.02	5.46 ± 1.73
YFP	0–10	1.33 ± 0.10	0.099 ± 0.011	1.044 ± 0.10	11.8 ± 0.92
	10–20	1.01 ± 0.09	0.082 ± 0.010	0.839 ± 0.10	10.3 ± 0.90
MFP	0–10	1.76 ± 0.16	0.102 ± 0.001	1.145 ± 0.01	19.7 ± 1.77
	10–20	1.64 ± 0.14	0.090 ± 0.007	1.104 ± 0.08	20.0 ± 1.67
YFP + R	0–10	1.69 ± 0.20	0.119 ± 0.003	1.105 ± 0.03	15.7 ± 1.90
	10–20	1.72 ± 0.31	0.088 ± 0.005	0.972 ± 0.09	21.4 ± 3.42
YFP + S	0–10	1.55 ± 0.25	0.217 ± 0.011	1.167 ± 0.17	18.4 ± 2.98
	10–20	1.45 ± 0.25	0.129 ± 0.006	1.230 ± 0.07	17.3 ± 3.09

Table 7 ANOVA of soil organic carbon, total nitrogen, and their stock capacities

Source	SS	*df*	MS	*F*	Eta squared
Soil organic carbon (SOC) (%)					
Plant cover	12.813	4	3.203	90.864**	0.879
Soil depth	0.251	1	0.251	7.117*	0.125
Plant cover × Soil depth	0.523	4	0.131	3.711*	0.229
Error	1.763	50	0.035		
Soil total nitrogen (STN) (%)					
Plant cover	0.058	4	0.014	242.253***	0.951
Soil depth	0.004	1	0.004	63.714***	0.560
Plant cover × Soil depth	0.003	4	0.001	13.979***	0.528
Error	0.003	50	5.934E−005		
SOC stock capacity (t C h^{-1})					
Plant cover	1813.973	4	453.493	98.948*	0.888
Soil depth	0.478	1	0.478	0.104	0.002
Plant cover × Soil depth	32.301	4	8.075	1.762	0.124
Error	229.156	50	4.583		
STN stock capacity (t N ha^{-1})					
Plant cover	6.570	4	1.643	226.962***	0.948
Soil depth	0.062	1	0.062	8.526**	0.146
Plant cover × Soil depth	0.145	4	0.036	5.007**	0.286
Error	0.362	50	0.007		

SS sum of squares, *df* degrees of freedom, *MS* mean squares

Asterisks indicate the level of significance: $*P<0.05$; $**P<0.01$; $***P<0.001$

in the following plot order: YFP + S (1.167 ± 0.17 t N ha^{-1}) > MFP (1.145 ± 0.01 t N ha^{-1}) > YFP + R (1.105 ± 0.03 t N ha^{-1}) > YFP (1.044 ± 0.10 t N ha^{-1}) > BSP (0.285 ± 0.03 t N ha^{-1}).

For the 10–20 cm soil layer, SOC content decreased in the following plot order YFP + R > MFP > YFP + S > YFP > BSP, while soil total nitrogen content decreased in the same plot order as seen for the top soil: YFP + R > YFP + S > MFP > YFP > BSP (Table 6). YFP + R had the highest SOC stock capacity, followed by MFP, YFP + S, YFP, and BSP, while YFP + S had the highest STN stock capacity, followed by MFP, YFP + R, YFP, and BSP (Table 6).

The soil organic carbon and total nitrogen contents and the N stock presented significant green cover × soil depth interactions, indicating that these soil values show different trends depending on the soil depth considered under the green cover (Table 7). Mean SOC stock values for all sites in the 0–20 cm soil layer were plotted against mean STN stock values for all sites. This relationship is illustrated in Fig. 3, which indicates that there was a strong

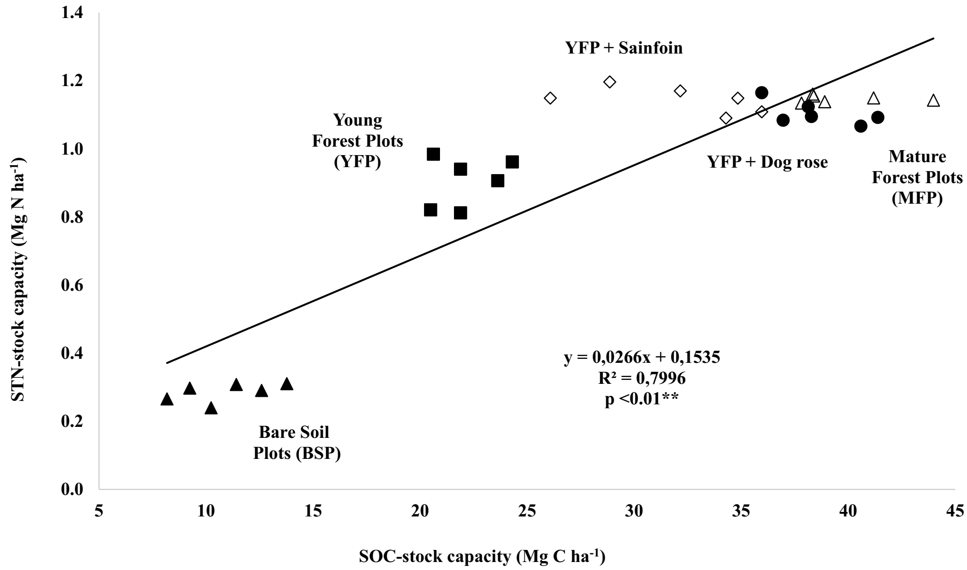

Fig. 3 Relationship between soil total N stock capacity and soil organic carbon stock capacity for the bare soil subplots (*BSP*; *unfilled circles*), the subplots with 7-year-old juvenile black pine cover (*YBP*; *unfilled diamonds*), the mature black pine subplots (*MBP*; *filled diamonds*), and the young black pine subplots with green cover from sainfoin (*YBS*; *unfilled triangles*) or dog rose (*YBR*; *unfilled squares*) in the 0–20 cm soil layer

positive relationship between mean STN stock capacity and mean SOC stock capacity. The sites with relatively high STN stock capacities also showed relatively high SOC stock capacities. As seen in Fig. 3, BSP, which had the lowest STN stock capacity, also had the lowest SOC stock capacity, whereas MFP, YFP + R, and YFP + S presented the highest STN stock capacities and the highest SOC stock capacities (Fig. 3). YFP, which had a moderate STN stock capacity, also showed a moderate SOC stock capacity.

Discussion

Changes in soil properties

The results of the present study indicated that combining black pine afforestation with green cover from dog rose or sainfoin (i.e., YFP + R and YFP + S) can help to reduce soil pH but increase the water holding capacity and the soil extractable P and K. The results also showed that the YFP + R and YFP + S sites had higher soil clay and silt contents but lower sand contents and soil bulk densities than the YFP and BSP sites.

Soil pH was reduced at the YFP + R and YFP + S sites. Bowren et al. (1995) noted that inoculated nodulated legumes acquire their nitrogen from the air (diatomic N) rather than from the soil as nitrate; the net effect of this is to reduce the pH of the soil. Soil pH is important because it affects the availability of nutrients to plants. Although the desirable soil pH range for optimum plant growth depends on the crop considered, a soil pH in the range 6.0–7.5 is generally acceptable for most plants, as most nutrients become available in this pH range. In the present study, the presence of green cover from dog rose or sainfoin reduced the pH of the top soil from 8.25 (BSP) to 7.01 (YFP + R) and 7.55 (YFP + S), and the pH of the subsoil from 8.21 (BSP) to 7.00 (YFP + R) and 7.12 (YFP + S).

The increase in WHC (of 18–35%; Table 4) observed in this study for the YFP + S and YFP + R sites as compared to the BSP and YFP sites could be due to the presence of vegetative cover. A number of authors have reported that shrub encroachment increased the soil water content by reducing the soil surface temperature (Moro et al. 1997), while others noted that shrub encroachment also improved soil structure (Pinto-Correia and Mascarenhas 1999) and nutrient contents beneath the shrub canopies (Simões et al. 2009; Tárrega et al. 2009). Some authors have stated that the development of vegetative cover in any area can result in a feedback process in which water availability facilitates further plant establishment, reducing erosion and elevating nutrient levels, leading to the progressive recovery of the degraded soil, as shown by Bienes et al. (2016). Yang et al. (2016) argued that the use of green cover plants when restoring degraded soil results in islands with increased soil porosity and soil moisture. Cerdà et al. (2015) reported that a patchy shrub distribution is crucial for controlling soil and water losses in Mediterranean ecosystems, as the shrubs reduce runoff connectivity. In the present study, the litter cover at the YFP + S and YFP + R sites probably facilitated the retention of soil moisture—a particularly important property in hot areas. According to the United States Department of Agriculture (USDA 2019), several legumes have aggressive taproots that can reach down to depths of 183–243 cm and can be 1.27 cm thick. Such root systems open up pathways deep into the soil. As shown by Eck et al. (2015), nitrogen-rich legume residues encourage earthworms, which burrow into the soil, creating further channels. These root channels and earthworm burrows can increase soil porosity, promoting the penetration of air and water deep into the soil, and they have the ability to recycle plant nutrients that are deep in the soil profile, as revealed by Drut et al (2018).

The mean soil bulk density at the YFP + R and YFP + S sites was approximately 19% (topsoil) and 16% (subsoil) less than that at the MFP and YFP sites, which may be mostly because the root systems of dog rose and sainfoin penetrate deeper and more densely into the soil than the root systems of young or mature black pine. On the other hand, soil bulk density was much higher at the BSP site (1.28 ± 0.06 g cm^{-3} for the topsoil and 1.39 ± 0.03 g cm^{-3} for the subsoil) than at the YFP + R and YFP + S sites, probably due to the lower root density in and reduced incorporation of leaf litter into the soil at the BSP site. According to many researchers (e.g., Acin-Carrera et al. 2013; Bienes et al. 2016), bulk density usually increases when the land is left alone. Cerdà et al. (2009) have stated that a lack of vegetative cover can increase soil erodibility and bulk density, which is a key reason for runoff initiation.

Chisci et al. (2001) noted that after 11 years, an Ah horizon 2–3 cm thick had formed under a shrub canopy due to the decomposition of root systems, which favored soil macroporosity and infiltration. In our study, we also noted the formation of an Ah horizon 4–5 cm thick under the green cover at the YFP + S and YFP + R sites, and the presence of this horizon seemed to increase soil extractable P and K. The increased nutrient levels at the YFP + S and YFP + R sites may also be a consequence of litter accumulation and decomposition. Dog rose and sainfoin are branched species with a lot of leaf biomass. The shedding of leaf tissue by these species leads to the accumulation of a lot of litter on the soil surface. When this litter decomposes, cations are released into the soil, increasing the concentrations of P and K within the rhizosphere. Litter decomposition is a key process in ecosystems. When a larger C fraction is released into the atmosphere, a smaller C fraction is transferred to humic substances that can be stored in the soil for a long time; N, P, and minerals can also be stored in the soil for reuse by plants (Berg and McClaugherty 2003). The accumulated organic matter also covers the soil surface under the dog rose or sainfoin, blocking the leaching of these nutrients from the soil surface. When the soil is transferred away by wind or water erosion, essential nutrients such as P, N, and K are lost. Zuazo and Pleguezuelo (2008) emphasized that the topsoil is usually relatively rich in nutrients, so eroded soil typically contains about three times more nutrients than the soil left on the eroded land. Many studies have indicated that the physical properties of the soil improve when legumes become established in the soil (Frame 2005; Carbonero et al. 2011). This improvement in the physical properties of the soil can be also attributed to increased soil aggregate stability. Some authors (e.g., Chaney and Swift 1984) have stated that the presence of soil organic matter facilitates the formation of soil aggregates and increases soil porosity, thus improving soil structure, which in turn enhances water infiltration and ultimately the overall productivity of the soil. In addition, increasing the amount of organic matter in the soil enhances root growth and stimulates the growth of important soil biota, as noted by Langdale et al. (1992).

Changes in the dispersion ratio

The results from the present study confirm those from other studies in which it was found that green cover canopies can save the soil from damage by the wind and raindrops (Malik et al. 2000), and our results are in agreement with a significant number of studies from around the world in which it was observed that soil erosion was reduced when vegetative cover was increased—an effect seen for a range of vegetation types (Zuazo and Pleguezuelo 2008). In the sites considered in the present study, the terraces containing only young black pines could not protect the soil from water and wind erosion; these pines only cover and protect the soil underneath and around them when they have reached 15–20 years of age (Boydak and Çalışkan 2015). However, naturally or artificially used sainfoin or naturally grown dog rose can shelter and fix the soil with its roots, reducing the energy of raindrops with their canopies, as stated by Andreu et al. (1998). Zuazo et al. (2011) attributed the importance of vegetative cover in erosion control to two main effects: (1) the direct mechanical protection of the soil surface by the canopy and litter cover, which intercept rainfall and consequently reduce the detachment of soil particles caused by the impacts of raindrops at the soil surface, and (2) the indirect improvement in the physical and chemical properties of the soil, essentially through the incorporation of soil organic matter.

Studies by Nunes and Seixas (2003) and Nearing et al. (2005) have indicated that climatic variability will increase due to global warming, resulting in more frequent and intense extreme weather events, which will inevitably increase erosion. Romero et al. (1998) noted that this trend could be especially threatening in areas in which precipitation is characterized by scarcity, torrential storms, and extreme variability in space and time. Díaz et al. (1994) proposed that, in semiarid areas such as those considered in the present study, the hot climate suppresses plant cover, which in turn reduces the input of organic matter into the soil to very low levels, leading to the development of poor soil structure. Under these conditions, Kaihura et al. (1999) have argued that the role of plant cover in protecting soil from erosion is crucial, since removing vegetation strongly increases surface runoff and sediment yield, causing the soil quality to deteriorate. Soil quality is an inherent attribute of the soil that can be inferred from specific characteristics and observations of the soil (e.g., compactability, erodibility, and fertility). The term also refers to the soil's structural integrity, which imparts resistance to erosion and the loss of plant nutrients and soil organic matter.

In the present study, it was clearly apparent that the soils in all of the experimental sites, including the mature (30-year-old) black pine plots, were erosive and at risk of erosion according to Middleton's dispersion ratio (a ratio > 15 is indicative of erosive soil). Compared to the soil dispersion ratio for the bare soil plot (29 for the top soil), the black pine terraces with green cover showed significantly ($P < 0.001$) reduced soil dispersion ratios (21 for dog rose cover and 22 for sainfoin cover). The soil dispersion ratios were, however, only 19 and 25 for the mature and young black pine plots without green cover. It is therefore clear that green cover from sainfoin or dog rose provided a much better physical barrier and suppressed erosion much more effectively than the use of black pine trees only on the terraces in the present study. The mature black pine trees on the terraces were approximately 30 years old and the young black pine trees on the terraces were 7 years old. However, within two years, the green cover achieved by planting sainfoin on the terraces had improved the soil quality and reduced the dispersion ratio to much lower than that in the young black pine only plot—almost down to the dispersion ratio of the soil in the mature black pine plot. Given that other researchers have reported similar findings that have demonstrated the utility and potential of green cover vegetation to reduce soil erosion, the results of the present study support the recommendation that green plant cover should be established on tree row plantation terraces to reduce soil erosion, improve soil quality, and increase SOC and STN stock capacities.

Changes in SOC content and SOC stock capacity

Other similar studies to the present study have shown that the SOC content can increase, decrease, or not change significantly in response to shrub encroachment and legume species establishment (Throop et al. 2013; Eldridge et al. 2012). The results obtained in this study showed that the presence of dog rose (a hermaphroditic shrub) and sainfoin (a perennial forage legume) significantly ($P < 0.05$) increased the SOC content and stock capacity. Compared to the BSP site, the SOC content was increased threefold at the YFP site and fourfold at the MFP, YFP + R, and YFP + S sites (Table 6). The SOC stock capacity also increased twofold at the YFP site, threefold at the YFP + S site, and fourfold at the YFP + R and MFP sites (Table 6). The accumulation of SOC that occurred under the black pine trees, the dog rose, and the sainfoin is mostly due to greater primary production, which increased SOC input into the soil from surface litter and roots in wooded areas, as stated by Archer et al. (2001) and Boutton et al. (2008).

Fenton et al. (2005) found that the presence of natural green cover leads to more biomass and augments the organic matter content and structural stability of the soil. Barrows and Kilmer (1963) reported that soil organic matter is among the first of the soil components to be removed by water and wind erosion because it is concentrated at the soil surface and has a low density. Thus, the soil surface can be protected against SOC and nutrient losses caused by sediment loss by introducing plant cover. The observed increase in soil organic matter and therefore soil quality due to the existence of plant cover agrees with the results of many other authors (Andreu et al. 1998; Durán et al. 2006; Rodríguez et al. 2009a). Therefore, plant cover is crucial to improving soil quality. Rodríguez et al. (2009b) also reported that litter decomposition and nutrient release from plant cover used to control soil erosion in the taluses of orchard terraces significantly enhanced soil fertility. In the present study, results showed that plant cover can increase soil organic carbon and total nitrogen as well as nutrients (soil extractable P and K) in the soil, as these were highest in the plots with sainfoin or dog rose cover, followed by the plots with young and mature black pine trees only (Tables 4 and 6), and were lowest in the bare soil plots. The particularly low C and nutrient contents in open areas without any plant cover can also be attributed to easy soil aggregate breakdown because the soil is more erodible, as stated by other researchers (Fenton et al. 2005). Low production leads to a low C input into the soil, which implies a low SOC content and thus a low SOC stock capacity. The soil structure then becomes poor and unstable and its WHC decreases, further intensifying soil erosion. On the other hand, the existence of plant cover leads to more organic residues, which increase the rugosity and the SOC content of the soil, and the presence of plant cover increases the percentage of the soil surface covered by vegetation.

Hassink (1997) hypothesized that soils may have a finite capacity to protect soil organic matter from decay; this maximum protective capacity is related to the maximum amount of soil organic matter that can be associated with silt and clay particles. According to several authors (Quiroga et al. 1996), organic carbon linked to coarse particles is less protected from oxidation than organic compounds that are linked to the clay and silt fractions. In the present study, the soil clay and silt contents at the YFP + R and YFP + S sites, which had the highest SOC values and stock capacities, were significantly ($P < 0.01$ and $P < 0.05$, respectively) higher than those at the BSP and YFP sites (Table 6). This difference underlines that carbon sequestration increases with soil clay content, and that this sequestration promotes stable aggregation and hence protects soil organic matter, as indicated by Feller and Beare (1997). Franzluebbers and Arshad (1996, 1997) also showed that the physical protection of soil organic matter within aggregates increases with the clay content. It is generally agreed that soil organic matter in microaggregates is better protected than that in macroaggregates (Krull et al. 2003). In that study, the authors found that microaggregates accounted for approximately 50% of all the protected C (the C within aggregates and the C associated with silt and clay).

Encroachment of the N-fixing forage legume *Onobrychis viciifolia* into the afforested black pine terraces (YFP + S) increased the total N content and stock in the soil (Table 6). Soil total N was increased sevenfold at the YFP + S site and fivefold at the YFP and YFP + R sites compared to the BSP site (Table 6). The STN stock capacity was increased fivefold at the YFP + S site and fourfold at the YFP, MFP, and YFP + R sites compared to the BSP site (Table 6). Sainfoin (*Onobrychis viciifolia*) is a perennial forage legume that is able to convert inorganic gaseous atmospheric nitrogen into bioavailable nitrogen compounds (ammonium), and therefore has the potential to bring additional N into the ecosystem. This ammonium can then be used directly by plants to produce proteins (Frame 2005). It is known that leguminous plant and seed tissues contain relatively high levels of protein. As stated by Frame (2005), this can be attributed to a legume's ability to supply most of its own nitrogen needs with the help of symbiotic rhizobia bacteria that live in its roots. Recent literature has shown that systems based on forage legumes have the ability to positively impact on the environment (Carbonero et al. 2011). Forage legumes have been shown to increase the efficiency of nitrogen use and to decrease nitrogen transit from the soil (Galloway et al. 2004). This finding is consistent with results from other ecosystems, where sites encroached upon by individual trees have been compared with open grassland (Ludwig et al. 2004; Hagos and Smit 2005). Chisci et al. (2001) noted that most crop residues contain much more carbon than nitrogen, but bacteria in the soil need both of these elements, so the nitrogen supplied by legumes facilitates the decomposition of crop residues in the soil and their conversion to soil organic matter, which can be used during plant growth.

The STN stock capacity showed a strong positive correlation with the SOC stock capacity in the soil (Fig. 3). This strong relationship between SOC and STN or the C/N ratio has been shown in many studies. De Vries et al. (2009) reported a positive relationship between N deposition and C stock capacity in European forests, whereas Nave et al. (2009) showed that a greater N input led to a lower C/N ratio in the forest floor for northern temperate forest soils. This strong correlation between SOC and STN in the soil should be considered in future investigations.

Conclusion

The present study has highlighted the impact of green cover plants (dog rose and sainfoin) on soil properties, the dispersion ratio, and the stock capacities of SOC and STN in black pine tree terraces, reflecting the need to protect these structures from soil loss by using plant cover. The results presented here support the findings of previous researchers that the development of vegetative cover involves a feedback process in which water availability facilitates further plant establishment, less erosion, increased nutrient levels, and thus the progressive recovery of the degraded soil. In semiarid environments, afforestation can be more difficult and slower due to the degraded soil, so it generally ends in failure when used as a land restoration tool. The trees also grow slowly and have only a limited ability to protect the soil while they are young. Grasses and shrubs, on the other hand, grow quickly, rapidly covering the soil surface. This alleviates the effects of splashing on the soil and reduces runoff. Therefore, the use of trees, shrubs, and grasses together on the terraces should help to protect the soil from erosion. Saving and restoring different plant communities on slopes in order to reduce soil erosion is vital, as this helps to maintain the fertility of the soil in pastureland. As shown in many studies, a loss of plant species diversity has important effects on the erosion resistance of slopes. The results obtained in the present study show that artificially planted sainfoin and (especially) natural grown dog rose, which are both species that produce dense cover above the soil surface (litter or canopy cover), exert a greater influence on SOC and STN stocks and reduce soil erosion to a greater extent than 7-year-old young black pine trees or even 30-year-old mature black pine trees. With proper care and management, natural or artificial leguminous and shrub species could provide year-round protection and minimize soil erosion from plantation terraces. The growth of these species can help to improve soil productivity by increasing soil organic matter, improving the soil structure, and increasing the water and nutrient-holding capacities of the soil.

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Compliance with ethical standards

Conflict of interest On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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