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Substratum properties and mosses in semi-arid environments. A case study from North Turkey

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Abstract – We investigated moss flora distribution and their relationship to substrates of a semi-arid environment in Cankiri, northwest Turkey. Moss samples were taken from soil surfaces, rock, and tree barks. Soil samples were taken from underneath mosses at 17 sites and soil texture, $CaCO_3$, pH, electrical conductivity, and soil organic matter were measured. Rock samples were collected from 15 different rock types and some mosses were collected from the oak barks. Identification of the moss specimens revealed the presence of 58 taxa belonging to 23 genera and 10 families – three species included in the Red Data Book of European Bryophytes. The relationship between moss occurrence patterns and terrestrial variables was evaluated by multiple linear regression analysis. No significant relationship could be established between *Syntrichia ruralis* and any of the studied terrestrial variables. Silt content correlated to the greatest number of moss taxa while pH could correlate with only one taxon. *Grimmia trichophylla* and *Syntrichia ruralis* were the most abundant species within the collected mosses and *Tortula revolvens* and *Ceratodon purpureus* were specific to calcareous soils in the study area.

Arid Lands / Mosses / Biological soil crusts / Multiple linear regression analysis / Soil physical and chemical properties / Çankiri

INTRODUCTION

Open spaces in many arid and semi-arid environments are commonly covered by biological soil crusts (BSCs) composed of cyanobacteria, algae, fungi, lichens, and bryophytes (mosses and liverworts) (Chamizo *et al.*, 2012). In arid and semi-arid landscapes, BSCs can comprise over 70% of the living ground cover vegetation layer (Rosentreter *et al.*, 2007). They grow in very thin layers (5-50 mm) either on the soil surface or underneath the surface (Rivera-Aguilar *et al.*, 2006). Therefore, some studies have mentioned that the presence and development of BSCs (Jafari *et al.*, 2004; Chamizo *et al.*, 2012) and specifically bryophytes can affect physicochemical characteristics of soil (Bahuguna *et al.*, 2012). Also, soil properties (organic matter and soil depth) may affect the diversity or richness of gypsophilous communities (Dana & Mota, 2006) and the presence or absence of $CaCO_3$ may affect the cryptogamic vegetation (Watson, 1918).

There are some reports about bryophyte crusts on calcareous and gypsiferous lands of arid and semi-arid regions around the world. Bryophytes were studied in arid (Downing & Selkirk, 1993), semi-arid (Guerra *et al.*, 1995;

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Maestre *et al.*, 2011) areas, and gypsum rich soils (Guerra *et al.*, 1995; Dana & Mota, 2006; Martinez *et al.*, 2006; Bogdanović *et al.*, 2009). Downing & Selkirk (1993) carried out bryophyte studies on calcareous soils and reported that environmental factors (soil texture, pH, conductivity, nutrient status, vascular plant vegetation, light level, leaf litter, and fire frequency) play a significant role in determining bryophyte distribution and Maestre *et al.* (2011) discussed ecology and the functional roles of BSCs. Guerra *et al.* (1995) demonstrated that gypsiferous outcrops in SE Spain supported the major biodiversity in arid zones of the Iberian Peninsula, including many bryophyte and lichen taxa.

The aim of this study was to investigate the distribution of mosses in semi-arid environments (Korubaşı hill and surroundings) in Çankırı, Turkey. The relationships between moss occurrence, soil, and topographic variables were evaluated. To our knowledge, this study is the only one conducted in the region with the above stated objectives.

MATERIALS AND METHODS

Study area

The Korubaşı hill and surroundings in the southwest part of Çankırı are distributed along 2800 ha and include some parts of the gypsic hills (Fig. 1-A). Based on 18 years of climatic data (1989-2007), the mean annual temperature is 10^{o}C, the mean monthly average ranging from 1ºC (January) to 22ºC (July-August); the average annual precipitation is 656 mm, with the maximum monthly precipitation (53 mm) in December and the minimum (21 mm) in July (Meteoroloji Genel Müdürlüğü, 2007) as seen in Fig. 1-B. The most abundant vascular plants in the study area are shrubs of *Paliurus spina-christi* Mill. and *Berberis vulgaris* L. Numerous vascular plant species are endemic in these zones, for example *Gypsophila germanicopolitana* Hub.-Mor., *Linum mucronatum* Bertol. subsp. *gypsicola* P.H.Davis var. *gypsicola, Centaurea germanicopolitana* Bornm., and *Campanula pinnatifida* var. *germanicopolitana* Hub.-Mor. (Ertuğrul, 2011).

Sampling and Analysis

Samples (soils, rocks, and mosses) were collected between September 2010 and November 2011. Forty-nine sampling sites were investigated in Korubaşı hill and surroundings (Fig. 1-A, Table 1). A stratified random sampling plan was applied. Different altitudes, aspects, vegetation, and steepness of landscapes were sampled from 785 to 1181 m height AMSL (altitude) in the study area. The exact location of a sampling site was chosen based on the existence of mosses. Soils and/ or rocks, and mosses were sampled concomitantly in the sampling site. Mosses were collected with a cutting tool on the surface of rocks, tree barks, and soils. Samples were preserved in plastic bag, and transported to the laboratory. Rock samples were identified according to Uz (2000) and Sür *et al.* (2009).

Soil and topographic variables and methods of their analysis were given in Table 2. Soil samples were collected just below the carpet of moss species at 0-1, 1-3, 3-10 cm depths at 17 sampling sites (51 soil samples were taken from

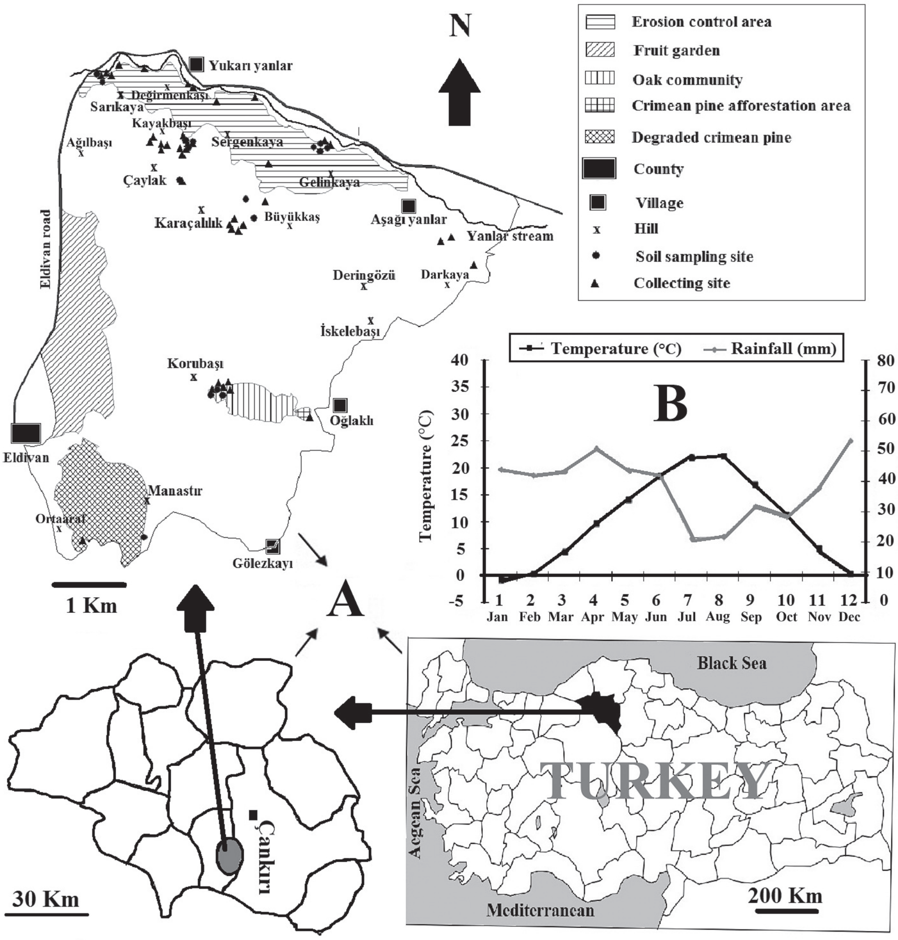

Fig. 1. Map of the study area (A) and climatic diagram (B) of Çankırı.

17 sampling points with exposed soil surfaces). Soil samples from three different depths allowed us to assess if any significant changes occurred in soil properties within the depth of 10 cm surface soil layer (Figueira *et al*., 2002; Aceto *et al*., 2003; Jafari *et al*., 2004). In the study area 58 moss taxa were observed and 23 of them were on the soils. However, 17 of 23 moss- observed soil surfaces could be sampled and 14 taxa were observed on these sampled sites. The remaining six sites could not be sampled as the soil was too shallow to sample. The altitude, geographical coordinates and substratum data for all moss species were recorded during the sampling.

In the laboratory, soil and moss debris were removed before the samples were air-dried. Mosses were identified at species and subspecies levels according to Smith (2004) and Heyn & Hernstadt (2004). Identified moss taxa were checked using the check-lists from Uyar & Çetin (2004) and Kürschner & Erdağ (2005) if

Table 1. Localization of the study sites. (SN): site number

SN	*Date*	*Localities*	*Altitude (m)*	*Latitude N*	*Longitude E*
1	30.09.2010	Kayakbaşı hill	1082	40° 33' 43.113"	33° 31' 40.784"
2	30.09.2010	Kayakbaşı hill	1077	40° 33' 44.124"	33° 31' 39.474"
3	30.09.2010	Kayakbaşı-Ağılbaşı hill	1029	40° 33' 58.991"	33° 31' 29.384"
4	30.09.2010	Kayakbaşı-Ağılbaşı hill	1026	40° 37' 46.393"	33° 31' 31.418"
5	30.09.2010	Kayakbaşı-Ağılbaşı hill	1019	40° 37' 46.658"	33° 31' 30.271"
6	30.09.2010	Ağılbaşı hill	1005	40° 34' 0.928"	33° 31' 24.296"
7	30.09.2010	Ağılbaşı hill	1001	40° 38' 22.417"	33° 31' 25.953"
8	04.11.2010	Korubaşı hill, Oğlaklı village	1181	40° 32' 9.923"	33° 31' 57.651"
9	04.11.2010	Korubaşı hill, Oğlaklı village	1176-1180	40° 32' 12.098"	33° 32' 4.172"
10	04.11.2010	Korubaşı hill, Oğlaklı village	1159	40° 32' 10.773"	33° 32' 10.282"
11	04.11.2010	Değirmen kaşı	838	40° 34' 35.108"	33° 31' 3.422"
12	04.11.2010	Değirmen kaşı	840	40° 34' 31.248"	33° 30' 56.290"
13	04.11.2010	Değirmen kaşı	846	40° 34' 30.956"	33° 30' 56.202"
14	04.11.2010	Sergenkaya hill	842	40° 34' 33.450"	33° 31' 18.679"
15	04.11.2010	Gelinkaya hill	840	40° 34' 20.304"	33° 32' 24.671"
16	08.06.2011	Oğlaklı village	1173	40° 32' 8.510"	33° 32' 1.678"
17	08.06.2011	Oğlaklı village	1170	40° 32' 7.783"	33° 32' 4.563"
18	08.06.2011	Oğlaklı village	1164	40° 32' 9.592"	33° 32' 6.107"
19	08.06.2011	Oğlaklı village	1115	40° 31' 57.098"	33° 32' 56.123"
20	08.06.2011	İskelebaşı hill	803	40° 33' 4.493"	33° 34' 35.655"
21	08.06.2011	İskelebaşı hill	814	40° 33' 4.758"	33° 34' 34.722"
22	20.06.2011	Yukarı Yanlar stream	813	40° 34' 31.825"	33° 30' 50.424"
23	20.06.2011	Yukarı Yanlar stream	843	40° 34' 31.459"	33° 30' 52.676"
24	20.06.2011	Yukarı Yanlar stream	843	40° 34' 31.865"	33° 30' 55.997"
25	20.06.2011	Yukarı Yanlar stream	833	40° 34' 26.360"	33° 31' 44.484"
26	20.06.2011	Yukarı Yanlar stream	822	40° 34' 24.961"	33° 31' 45.366"
27	20.06.2011	Yukarı Yanlar stream	819	40° 34' 27.384"	33° 32' 1.633"
28	20.06.2011	Aşağı Yanlar stream	785	40° 34' 0.076"	33° 33' 3.804"
29	20.06.2011	Aşağı Yanlar stream	793	40° 34' 0.712"	33° 33' 6.403"
30	20.06.2011	Aşağı Yanlar stream	779	40° 33' 59.013"	33° 33' 8.984"
31	29.06.2011	Sergenkaya hill	1011	40° 33' 55.436"	33° 31' 40.881"
32	29.06.2011	Sergenkaya hill	1029	40° 33' 57.540"	33° 31' 41.918"
33	29.06.2011	Sergenkaya hill	1029	40° 34' 0.835"	33° 31' 44.793"
34	29.06.2011	Sergenkaya hill	1012	40° 34' 1.815"	33° 31' 43.227"
35	29.06.2011	Sergenkaya hill	1012	40° 34' 3.444"	33° 31' 41.624"
36	08.10.2011	Karaçalılık-Büyükkaş hill	1111	40° 33' 25.230"	33° 32' 11.684"
37	08.10.2011	Karaçalılık-Büyükkaş hill	1109	40° 33' 24.938"	33° 32' 11.724"
38	08.10.2011	Karaçalılık-Büyükkaş hill	1093	40° 33' 23.384"	33° 32' 11.159"
39	08.10.2011	Karaçalılık-Büyükkaş hill	1096	40° 33' 21.925"	33° 32' 10.978"
40	08.10.2011	Karaçalılık-Büyükkaş hill	1089	40° 33' 21.596"	33° 32' 12.038"
41	08.10.2011	Karaçalılık-Büyükkaş hill	1074	40° 33' 21.410"	33° 32' 17.139"
42	08.10.2011	Karaçalılık-Büyükkaş hill	1087	40° 33' 26.990"	33° 32' 23.732"
43	08.10.2011	Karaçalılık-Büyükkaş hill	1053	40° 33' 33.867"	33° 32' 30.336"
44	08.10.2011	Karaçalılık-Büyükkaş hill	975	40° 33' 46.698"	33° 32' 19.000"
45	08.10.2011	Karaçalılık-Büyükkaş hill	949	40° 33' 50.802"	33° 32' 15.376"
46	09.10.2011	Darkaya hill	809	40° 33' 17.214"	33° 34' 21.095"
47	09.10.2011	Darkaya hill	835	40° 33' 15.591"	33° 34' 14.915"
48	19.11.2011	Ortaaraf	1083	40° 31' 2.685"	33° 30' 40.157"
49	19.11.2011	Manastır hill	1181	40° 30' 53.710"	33° 31' 35.970"

Table 2. Descriptions of soil and topographic variables

Variables	*Sampling*	*Method of Analysis*	*Unit*	*Code*	*Description*
Sand	From 0-10 cm soil depth	Mechanical analysis with hydrometer	%	–	–
Silt	From 0-10 cm soil depth	Mechanical analysis with hydrometer	%	–	–
Clay	From 0-10 cm soil depth	Mechanical analysis with hydrometer	%	–	–
FC	From 0-10 cm soil depth	With Pressure plate apparatus	%	–	–
WP	From 0-10 cm soil depth	With Pressure plate apparatus	%	–	–
PAW	From 0-10 cm soil depth	Calculated	%	–	FC-WP
pH	From 0-10 cm soil depth	Soil-distilled water suspension (1:5)	–	–	–
EC	From 0-10 cm soil depth	Soil-distilled water suspension (1:5)	dS m^{-1}	–	–
$CaCO_3$	From 0-10 cm soil depth	With Scheibler Calcimeter	%	–	–
SOM	From 0-10 cm soil depth	Wet processing	%	–	–
Gypsum	From 0-10 cm soil depth	Acetone method	%	–	–
Altitude	GPS	–	–	AMSL	From sea level
Sine of aspect	GPS	Calculated	–	–	Equation 1 in the text
Cosine of aspect	GPS	Calculated	–	–	Equation 2 in the text

GPS: Global Positioning System; FC: Field capacity; WP: Wilting point; PAW: Plant available water content; EC: Electrical conductivity; SOM: Soil organic matter

they already exist in Turkey's list or not. The nomenclature of mosses follows Hill *et al*. (2006). The moss samples are kept in the private collection of the first author (G. Abay) in the Department of Forestry Engineering, Faculty of Forestry at Çankırı Karatekin University. Soil samples were air-dried in the laboratory, cleaned and sieved through a 2.0 mm screen, and stored in plastic bags. Fifty one soil samples were analysed for clay, silt, and sand contents by the hydrometer method (Gee & Bauder, 1986) and for soil organic matter (SOM) content by the method of Nelson & Sommers (1982). The soil samples were also analysed for $CaCO_3$ content using a Scheibler Calcimeter (Allison & Moodie, 1965), gypsum content by acetone method (Porta, 1998), soil water electrical conductivity (EC) and soil water pH with a glass electrode in soil-distilled water suspension (1:5) (McLean, 1982). Using a pressure plate apparatus, water contents were measured at – 0.033 MPa and soil water pressure at – 1.5 MPa (Klute, 1986).

Statistical Analysis

To determine the relationship between mosses, soil properties, and topographic variables, a multiple linear regression analysis was applied using the SPSS 20.0 software (SPSS Institute Inc., 2012). Since only 17 of 49 sampling sites were located in spots with at least 10 cm depth, only these 17 sampling points were considered in the statistical analysis. To determine the data distribution and variability of the soil and topographic variables, summary statistics (minimum, maximum, mean, standard deviation, coefficient of variance, and skewness) were calculated. After summary statistics of soil properties and ecological variables were calculated, a step-wise multiple linear regression analysis was conducted. Soil properties and topographic variables were used as independent variables and mosses were used as dependent variables. The significance level of 95% was considered in determining the significant variables. The Value of Variance Inflation Factors (VIFs) was calculated to detect and remove co-linearity between variables. VIF measures the variance of the estimated coefficients as a result of correlation between the independent variables. If no correlation exists between two variables, then the corresponding VIF will be 1. If a VIF is around five or greater, there is a strong co-linearity between variables (Coakes, 2005). Since soil properties appeared homogeneous along depth gradient, we used means of the values of soil samples at different depths for each sampling site.

For statistical analysis, aspect values were converted to sine and cosine values. Jenness (2007) stated that variables of sine and cosine values change depending on direction and sine values change between –1 (at due west) to 1 (at due east) while cosine values change between –1 (at due south) and 1 (at due north). The azimuth angle of the aspect was calculated to the southeast, and the corresponding aspect was quantified using Equations 1 and 2. N to E aspect represents 0º-90º azimuth; E to SE, 91º-125º azimuth; NW to N, 325º-359º azimuth; SE to NW, 126º-324º azimuth (Carmean, 1965).

Sine of aspect = $[\mathrm{Sin}\ (\theta_1\ (+1)] \times 100$ [Eq. 1]

Cosine of aspect = $[\mathrm{Cos}\ (\theta_2+1)] \times 100$ [Eq. 2]

Where,

θ_1= the azimuth angle of the aspect to the southeast and

θ_2= twice the azimuth angle of the aspect to the southeast.

RESULTS

The 180 moss samples were identified and classified into 58 taxa belonging to 23 genera and 10 families (43 acrocarpous and 15 pleurocarpous species) (Table 3). The family Pottiaceae ranked first in terms of genera and species representation, followed by Brachytheciaceae with 10 taxa, and Grimmiaceae with 9 taxa. No liverworts and hornworts were detected during the sampling.

Representatives of *Pottiaceae* were particularly common in the soil crusts of the study area, including the different moss species belonging to the genera *Didymodon*, *Bryoerythrophyllum*, *Pleurochaete*, *Pterygoneurum*, *Weissia* and *Tortella* other than *Syntrichia*, *Tortula*, and *Crossidium*. The most common genera on the gypsiferous soils were *Syntrichia*, *Tortula,* and *Crossidium*. The moss *Syntrichia caninervis* var. *gypsophila* and the moss community of *S. caninervis* var. *gypsophila* – *Ceratodon purpureus* – *Tortula revolvens* occurred in gypsum rich areas. *C. purpureus* formed pure stands in some places. In some cases, it was found in association with *Encalypta vulgaris*, *Grimmia trichophylla*, *S. caninervis* var. *gypsophila*, and *T. revolvens* in different localities of the study area.

Table 3. The moss taxa list in the study area

Families	*Moss Taxa*	*Site Number*	*Substrata*	*Collector Number*
Pottiaceae	*Syntrichia caninervis* var. *caninervis*	45	Colluvial soil	ABAY 1600
Pottiaceae	*Syntrichia caninervis* var. *gypsophila*	31, 37, 41, 44, 45, 46, 47	Sandstone, gypsum, colluvial soil on gypsum, gypsiferous soil and limestone	ABAY 1556, 1581, 1590, 1591, 1598, 1602, 1604
Pottiaceae	*Syntrichia latifolia*	6	Serpentine	ABAY 1446
Pottiaceae	*Syntrichia norvegica*	9	Oak barks	ABAY 1450
Pottiaceae	*Syntrichia princeps*	4	Soil layer of 1 cm on basalt	ABAY 1447
Pottiaceae	*Syntrichia ruralis*	1, 2, 19, 23, 25, 28, 29, 31, 32, 34, 40, 49	Claystone, gypsum, soil, conglomerate, limestone, pebblestone, red limestone,	ABAY 1439, 1440, 1441, 1442, 1532, 1533, 1536, 1538, 1557, 1559, 1565, 1588, 1612
Pottiaceae	*Syntrichia virescens*	9, 15, 36	Oak barks, roots of Crimean pine, gypsiferous sandstone	ABAY 1448, 1449, 1585
Pottiaceae	*Tortula inermis*	11, 12, 19, 24, 30, 32, 33, 34, 36, 45, 48	Serpentine, andesite, conglomerate, colluvial soil on limestone and red limestone, pebblestone, gypsiferous limestone, sandstone, colluvial soil	ABAY 1443, 1444, 1445, 1541, 1561, 1563, 1564, 1582, 1584, 1599, 1609
Pottiaceae	*Tortula brevissima*	43	Gypsiferous sandstone	ABAY 1593
Pottiaceae	*Tortula cuneifolia*	6	Serpentine	ABAY 1451
Pottiaceae	*Tortula muralis*	18, 38	Colluvial soil on gypsum, soil	ABAY 1452, 1586
Pottiaceae	*Tortula revolvens*	44	Gypsiferous soil	ABAY 1597
Pottiaceae	*Tortula lanceola*	32	Pebblestone, colluvial soil on pebblestone	ABAY 1558
Pottiaceae	*Didymodon acutus*	20, 26	Gypsum, colluvial soil on calcareous soil, limestone	ABAY 1455, 1528, 1529
Pottiaceae	*Didymodon ferrugineus*	22	Colluvial soil on rock	ABAY 1520
Pottiaceae	*Didymodon vinealis*	24, 25, 30	Colluvial soil on limestone, limestone, soil on conglomerate	ABAY 1523, 1534
Pottiaceae	*Crossidium crassinerve*	5, 6, 40	Claystone, serpentine, colluvial soil on gypsum	ABAY 1454, 1587
Pottiaceae	*Crossidium squamiferum* var. *pottioideum*	24, 26, 43	Limestone, colluvial soil on limestone, gypsum	ABAY 1522, 1527, 1594
Pottiaceae	*Crossidium squamiferum* var. *squamiferum*	26, 30	Limestone, conglomerate, soil on conglomerate	ABAY 1530, 1537, 1539, 1540

Table 3. The moss taxa list in the study area *(continued)*

Families	*Moss Taxa*	*Site Number*	*Substrata*	*Collector Number*
Pottiaceae	*Bryoerythrophyllum recurvirostrum*	4, 24	Basalt, limestone	ABAY 1453, 1526
Pottiaceae	*Pleurochaete squarrosa*	27,32,28	Serpentine, colluvial soil on serpentine, on soil, colluvial soil on pebblestone	ABAY 1531, 1535, 1562
Pottiaceae	*Pterygoneurum ovatum*	21, 32	Limestone, colluvial soil on pebblestone	ABAY 1457, 1560
Pottiaceae	*Weissia controversa*	24	Limestone	ABAY 1525
Pottiaceae	*Tortella tortuosa*	12, 22, 24	Andesite, colluvial soil on rock, limestone	ABAY 1456, 1521, 1524
Brachytheciaceae	*Brachythecium erythrorrhizon*	16	Soil	ABAY 1489
Brachytheciaceae	*Brachythecium glareosum*	22	Colluvial soil	ABAY 1506
Brachytheciaceae	*Brachythecium mildeanum*	15, 16	Soil, oak barks, serpentine	ABAY 1486, 1487, 1488
Brachytheciaceae	*Sciuro-hypnum plumosum*	11	Serpentine	ABAY 1485
Brachytheciaceae	*Sciuro-hypnum populeum*	22	Colluvial soil on rock	ABAY 1505
Brachytheciaceae	*Brachytheciastrum velutinum*	9	Oak barks	ABAY 1483
Brachytheciaceae	*Homalothecium aureum*	25	Limestone	ABAY 1507
Brachytheciaceae	*Homalothecium lutescens*	22, 28, 35	Sandstone, soil	ABAY 1503, 1504, 1508
Brachytheciaceae	*Homalothecium philippeanum*	33	Limestone	ABAY 1549, 1550
Brachytheciaceae	*Homalothecium sericeum*	10, 16, 22, 48	Oak barks, colluvial soil, limestone	ABAY 1484, 1490, 1502, 1611
Grimmiaceae	*Grimmia anodon*	1, 31, 43, 46, 47	Claystone, sandstone, limestone, gypsiferous limestone	ABAY 1467, 1579, 1592, 1601, 1603
Grimmiaceae	*Grimmia funalis*	7, 24, 31, 32	Claystone, colluvial on limestone, sandstone, pebblestone	ABAY 1469, 1514, 1573, 1575
Grimmiaceae	*Grimmia montana*	47	Gypsiferous limestone	ABAY 1605
Grimmiaceae	*Grimmia ovalis*	12, 14, 33, 34	Andesite, basalt, limestone, colluvial soil on red limestone	ABAY 1472, 1473, 1566, 1569
Grimmiaceae	*Grimmia pulvinata*	1, 4, 11, 18, 25, 32	Claystone, basalt, serpentine, colluvial soil, limestone and pebble stone	ABAY 1465, 1468, 1471, 1475, 1512, 1571

Table 3. The moss taxa list in the study area *(continued)*

Families	*Moss Taxa*	*Site Number*	*Substrata*	*Collector Number*
Grimmiaceae	*Grimmia trichophylla*	1, 8, 16, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 34, 36, 48	Sandstone, claystone, altered andesitic basalt, soil, limestone, colluvial soil on serpentine, conglomerate, pebblestone, limestone assimilation by basaltic	ABAY 1466, 1470, 1474, 1509, 1510, 1511, 1513, 1517, 1518, 1519, 1567, 1568, 1570, 1576, 1577, 1578, 1580, 1583, 1607, 1608
Grimmiaceae	*Schistidium agassizii*	31	Limestone	ABAY 1574
Grimmiaceae	*Schistidium atrofuscum*	24	Limestone	ABAY 1516
Grimmiaceae	*Schistidium trichodon*	24, 32	Colluvial soil on limestone, pebblestone	ABAY 1515, 1572
Orthotrichaceae	*Orthotrichum affine*	3, 8, 9, 16	Oak barks, serpentine, claystone	ABAY 1477, 1478, 1479, 1482
Orthotrichaceae	*Orthotrichum anomalum*	33	Limestone	ABAY 1544
Orthotrichaceae	*Orthotrichum cupulatum*	33	Pebblestone	ABAY 1543
Orthotrichaceae	*Orthotrichum diaphanum*	40	Gypsum	ABAY 1589
Orthotrichaceae	*Orthotrichum rupestre*	4	Basalt	ABAY 1476
Orthotrichaceae	*Orthotrichum speciosum*	9, 16	Oak barks	ABAY 1480, 1481
Hypnaceae	*Hypnum cupressiforme* var. *cupressiforme*	17, 48	Soil	ABAY 1610
Hypnaceae	*Hypnum cupressiforme* var. *lacunosum*	4, 12, 14, 17, 22, 23, 30, 33	Basalt, andesite, soil, conglomerate, limestone, sandstone	ABAY 1458, 1459, 1460, 1461, 1462, 1494, 1495, 1496, 1551, 1552
Hypnaceae	*Hypnum vaucheri*	26	Limestone	ABAY 1491
Ditrichaceae	*Ceratodon purpureus*	25, 27, 29, 31, 34, 44	Limestone, serpentine, conglomerate, red limestone, gypsiferous soil	ABAY 1497, 1498, 1500, 1553, 1555, 1596
Ditrichaceae	*Ditrichum flexicaule*	13, 30, 33	Altered andesitic rock, conglomerate, limestone	ABAY 1463, 1501, 1554
Bryaceae	*Bryum caespiticium*	22, 34, 35, 48	Colluvial soil on rock, limestone, soil	ABAY 1492, 1547, 1548, 1606
Encalyptaceae	*Encalypta vulgaris*	26, 27, 33	Limestone, serpentine	ABAY 1493, 1499, 1542
Pterigynandraceae	*Habrodon perpusillus*	33, 34	Pebblestone, limestone and red limestone	ABAY 1545, 1546
Leucodontaceae	*Leucodon sciuroides*	12	Andesite	ABAY 1464

Many of the studied moss species were found on sandstone, conglomerate, pebblestone, serpentine, basalt, andesite, gyprock, and limestone rocks. *Grimmia trichophylla* was found on various rock types in open areas and constituted 15% of the identified mosses. *Syntrichia ruralis*, the second most abundant moss species in the study area, preferred various rock substrates besides soil. It constituted 11% of the collected mosses. *Tortula inermis* was frequently observed in the partial shades of various rocks in the Korubaşı hill and surroundings. Approximately 10% of the observed mosses corresponded to *T. inermis. Hypnum cupressiforme* var. *lacunosum* was also abundant in the study area on magmatic and sedimentary rocks and soil surfaces. *S. caninervis* var. *gypsophila* was generally observed on gypsum rich soils, sandstone, and limestone in open areas.

Results of the multiple linear regression analysis are shown on Table 4. *Brachythecium erythrorrhizon*, *B. glareosum, Grimmia trichophylla*, *Homalothecium lutescens, H. sericeum, Hypnum cupressiforme* var. *cupressiforme, H. cupressiforme* var. *lacunosum*, *Pleurochaete squarrosa*, *Syntrichia caninervis* var. *gypsophila*, *Tortula revolvens*, *S. ruralis, Ceratodon purpureus*, *Orthotrichum affine, B. mildeanum* correlated to soil and landscape attributes. Since only these taxa occurred on the sampled soil surfaces, we used only them in the multiple linear regression analysis between soil properties, topographical variables, and moss species. Some of the studied mosses correlated with only one variable while others correlated with several variables. For example, *B. glareosum* and *H. sericeum* only correlated significantly to silt content, *Hypnum cupressiforme* var. *cupressiforme* related only to altitude, and *H. cupressiforme* var. *lacunosum* only related to SOM. Table 4 shows that sand, silt, clay, and $CaCO_3$ contents, EC, and pH of the soils changed little with depth, suggesting that the mean of the soil parameters taken from three depths (0-1, 1-3, and 3-10 cm) at a sampling site could be used in a multiple linear regression analysis. The SOM, wilting point (WP) and field capacity (FC) somehow changed from 0-1 cm to 1-3 cm soil depth, which was attributed to the fact that SOM increased the water holding capacity of the soils.

Soil physical properties correlated to more moss species than soil chemical properties. Silt content of the soils significantly correlated to seven different mosses. However, not all of the seven mosses correlated positively to silt content. For example, *Brachythecium erythrorrhizon*, *Grimmia trichophylla*, *Orthotrichum affine*, and *Brachythecium mildeanum* had a negative correlation with silt while *B. glareosum*, *Homalothecium lutescens*, and *H. sericeum* had a positive correlation. Three mosses were negatively and concomitantly related to WP and silt content, indicating that increased silt content would promote WP. Similarly to SOM, soil pH correlated to only one moss species (*G. trichophylla*), and soil EC correlated to two moss species (*O. affine* and *B. mildeanum*).

Soil gypsum and $CaCO_3$ contents significantly related to some of the studied mosses. The gypsum content of the soils positively correlated to *Syntrichia caninervis* var. *gypsophila*, *Tortula revolvens*, and *Ceratodon purpureus*, while it negatively correlated to *Homalothecium lutescens*. Interestingly, *S. caninervis* var. *gypsophila*, *T. revolvens*, and *C. purpureus*, which positively correlated to gypsum, also positively correlated to $CaCO_3$ content of the studied soils.

Similarly to soil chemical variables, topographic variables also correlated significantly to a few mosses. Altitude and cosine of the aspect significantly correlated to the existence of mosses in the study area (Table 4). *Hypnum cupressiforme* var. *cupressiforme*, *Orthotrichum affine,* and *Brachythecium mildeanum* correlated positively to altitude. *Syntrichia ruralis* and *Grimmia trichophylla* distributed independently of altitude in the area. Cosine of the aspect

Table 4. Parameters of the "best fit" regression models of soil properties and topographic variables. (R^2_a): adjusted coefficient of determination; (SE): standard error; t statistics is probability values, (VIFs): variance inflation factors

Moss Taxa	*Independent Variables*	*Coefficients of Independent Variables*	*SE of Variables*	*t-statistics*	*p-value*	*VIFs*	*The goodness of-fit statistics*
Brachythecium erythrorrhizon	Silt	– 0.021	0.007	– 3.140	0.003	1.004	$R^2_a = 0.197$
	Cosine of aspect	0.001	0.000	2.288	0.027	1.004	$Sy \cdot x = 0.21294$
Brachythecium glaerosum	Constant	– 0.405	0.184	– 2.197	0.033		$R^2_a = 0.099$
	Silt	0.018	0.007	2.554	0.014	1.000	$Sy \cdot x = 0.22551$
Grimmia trichophylla	WP	– 0.054	0.011	– 4.829	0.000	1.153	
	Clay	0.024	0.005	4.439	0.000	1.160	$R^2_a = 0.462$
	Silt	– 0.045	0.011	4.246	0.000	1.169	$Sy \cdot x = 0.31435$
	pH	– 1.143	0.364	– 3.137	0.003	1.162	
Homalothecium lutescens	Constant	– 1.357	0.304	– 4.457	0.000		$R^2_a = 0.404$
	Silt	0.067	0.012	5.630	0.000	1.149	$Sy \cdot x = 0.35514$
	Gypsum	– 0.033	0.008	– 3.953	0.000	1.149	
Homalothecium sericeum	Silt	0.018	0.007	2.554	0.014	1.000	$R^2_a = 0.099$ $Sy \cdot x = 0.22551$
Hypnum cupressiforme var. *cupressiforme*	Constant	– 0.446	0.192	– 2.327	0.024		$R^2_a = 0.109$
	Altitude	0.001	0.000	2.671	0.010	1.000	$Sy \cdot x = 0.22428$
Hypnum cupressiforme var. *lacunosum*	SOM	0.035	0.015	2.332	0.024	1.000	$R^2_a = 0.082$ $Sy \cdot x = 0.22774$
Pleurochaete squarrosa	Cosine of aspect	– 0.003	0.001	– 4.690	0.000	1.088	$R^2_a = 0.415$
	Sand	0.002	0.001	2.442	0.018	1.088	$Sy \cdot x = 0.24886$
Syntrichia caninervis var. *gypsophila*	Gypsum	0.046	0.002	19.889	0.000	1.067	$R^2_a = 0.900$
	$CaCO_3$	0.004	0.002	2.235	0.030	1.067	$Sy \cdot x = 0.10216$
Tortula revolvens	Gypsum	0.022	0.004	5.577	0.000	1.067	$R^2_a = 0.454$
	$CaCO_3$	0.006	0.003	2.020	0.049	1.067	$Sy \cdot x = 0.17558$
Syntrichia ruralis	No significant relationship was found between this species and any of the variables						
Ceratodon purpureus	Gypsum	0.022	0.004	5.577	0.000	1.067	$R^2_a = 0.454$
	$CaCO_3$	0.006	0.003	2.020	0.049	1.067	$Sy \cdot x = 0.17558$
Orthotrichum affine	Silt	– 0.021	0.008	– 2.614	0.012	1.309	
	Altitude	0.001	0.000	4.898	0.000	1.409	$R^2_a = 0.522$
	WP	– 0.024	0.008	– 2.952	0.005	1.196	$Sy \cdot x = 0.22502$
	EC	0.336	0.129	2.598	0.013	1.215	
Brachythecium mildeanum	Silt	– 0.021	0.008	– 2.614	0.012	1.309	
	Altitude	0.001	0.000	4.898	0.000	1.409	$R^2_a = 0.522$
	WP	– 0.024	0.008	– 2.952	0.005	1.196	$Sy \cdot x = 0.22502$
	EC	0.336	0.129	2.598	0.013	1.215	

correlated positively to *B. erythrorrhizon* and negatively to *Pleurochaete squarrosa*. No correlation was established between mosses and the sine of the aspect. The correlation between mosses and cosine of the aspect was somewhat weak although it was significant.

Orthotrichum affine and *Brachythecium mildeanum* correlated to the same variables (silt content, altitude, WP, and EC), indicating that these two mosses were sensitive to both soil and topographic variables, and thus may co-exist in similar conditions. Therefore, these mosses may only be found on soils with high EC, low silt, and low WP on higher altitudes in the study area. Similar to *O. affine* and *B. mildeanum*, *Grimmia trichophylla* was sensitive to four soil variables but was not sensitive to any of the studied topographic variables (Table 4).

Four mosses (*Brachythecium glareosum*, *Homalothecium sericeum*, *Hypnum cupressiforme* var. *cupressiforme*, *H. cupressiforme* var. *lacunosum*) correlated significantly to only one variable. *B. glareosum* and *H. sericeum* only correlated to soil silt content, *H. cupressiforme* var. *lacunosum* correlated to SOM, and *H. cupressiforme* var. *cupressiforme* only correlated to altitude. These are very important variables that may influence solely the existence of these mosses. *Syntrichia caninervis* var. *gypsophila*, *Tortula revolvens*, and *Ceratodon purpureus* may need similar conditions. These three mosses grow on gypsum and $CaCO_3$ rich soils.

Soils of the study area are generally rich in clay and sand (Table 5). The coefficient of variation calculated for the soil variables showed that SOM, FC, WP, and plant available water contents varied and were skewed less at 0-1 cm soil depth than at 1-3 and 3-10 cm depths. The topographic variables such as altitude, sine and cosine of the aspect varied moderately (Webster, 2001; Table 5).

DISCUSSION

Previous and ongoing studies about BSCs in arid and semi-arid areas around the world are providing important insights regarding which genera and different BSCs occurred. Rivera-Aquilar *et al.* (2006) studied the distribution and composition of BSCs of Tehuacán valley, Puebla in Mexico and found 19 mosses of BSCs. *Weissia controversa* reported by the authors on sandy soils of Mexico occurred on limestone in our study area. The mentioned moss was infrequent both in Tehuacán valley and Korubaşı hill and surroundings. In North America, 52 mosses of BSCs have been described and the most frequently cited moss genera were *Bryum*, *Didymodon*, *Crossidium,* and *Ceratodon* (Belnap & Lange, 2001). Moss crusts occurred in large areas of exposed substrata in the study area. These mosses usually appear black, reddish-brown, greenish brown, green and yellowish green due to the differences in moss pigments and degree of dehydration. Mosses form either short (e.g. *Ceratodon purpureus*) or tall forms (e.g. *Syntrichia ruralis*) in terms of morphological groups (Belnap *et al.*, 2001).

There are some isolated gypsiferous and calcareous localities in the study area and in various parts of the world. Watson (1913) found *Didymodon tophaceus* (Brid.) Lisa on calcareous habitat, but the species was not found in the present study on the studied habitat. However, other species of *Didymodon* (*D. acutus*, *D. ferrugineus* and *D. vinealis*) occurred in the study area. In Watson's study, xerophytic moss inhabiting exposed rock surfaces were species of *Grimmia*, *Tortula Weissia*, *Encalypta*, etc. These genera were also found in our study area. *Homalothecium sericeum* of the Korubaşı hill and surroundings was also observed on the trees (such as oak) in the open areas of the aforementioned study.

Table 5. Summary statistics for soils below mosses and for topographic variables (n = 17). (FC): field capacity (volumetric); (WP): wilting point (volumetric); (PAW): plant available water content (volumetric); (EC): electrical conductivity; (SOM): soil organic matter; (N): sample numbers; (CV): coefficient of variation

Variables	*Depths (cm)*	*Minimum*	*Maximum*	*Mean*	*Standard Deviation*	*CV. %*	*Skewness*
Clay (%)	0-1	34.0	55.0	41.2	6.88	16.7	0.758
	1-3	27.0	57.0	39.8	8.88	22.2	0.615
	3-10	22.0	60.0	41.2	10.06	24.4	– 0.345
Silt (%)	0-1	17.0	33.0	25.7	5.05	19.6	0.119
	1-3	17.0	33.0	26.4	4.67	17.6	– 0.839
	3-10	20.0	32.0	25.3	4.01	15.8	0.350
Sand (%)	0-1	15.0	43.0	33.0	8.60	26.0	– 0.612
	1-3	15.0	45.0	33.6	8.68	25.8	– 0.681
	3-10	13.0	46.0	33.4	10.15	30.3	– 0.508
FC (%)	0-1	29.5	46.3	34.3	5.06	14.7	0.877
	1-3	24.9	43.5	29.0	5.36	18.4	1.653
	3-10	22.9	43.6	28.0	5.61	19.9	1.470
WP (%)	0-1	15.2	31.1	21.3	4.08	19.1	0.640
	1-3	14.0	29.4	17.0	3.90	22.8	2.460
	3-10	14.1	29.4	17.2	3.78	21.9	2.304
PAW (%)	0-1	7.6	16.4	13.0	2.53	19.4	– 0.595
	1-3	9.9	16.5	11.9	2.15	17.9	1.019
	3-10	6.6	14.3	10.8	2.38	21.9	0.150
pH	0-1	7.19	7.63	7.39	0.11	1.61	– 0.511
	1-3	7.44	7.72	7.52	0.07	1.01	0.345
	3-10	7.49	7.70	7.57	0.06	0.84	0.263
EC (dS m^{-1})	0-1	0.373	1.335	1.080	0.286	26.482	– 1.751
	1-3	0.436	1.337	0.957	0.245	25.685	– 1.024
	3-10	0.440	1.296	0.943	0.255	27.124	– 0.839
$CaCO_3$ (%)	0-1	3.87	32.53	12.115	9.029	74.524	0.772
	1-3	3.73	27.77	13.365	9.094	68.046	0.155
	3-10	4.02	25.66	11.837	8.201	69.288	0.343
SOM (%)	0-1	3.5	9.0	6.2	1.76	28.2	0.142
	1-3	2.1	7.0	3.9	1.53	39.0	0.619
	3-10	1.3	5.9	2.7	1.56	56.9	1.099
Gypsum (%)	0-1	0.0	14.3	1.5	4.28	269.2	2.678
	1-3	0.0	20.1	2.1	5.95	272.9	2.704
	3-10	0.0	30.1	3.0	8.62	278.6	2.777
Altitude		785.0	1181.0	945.8	158.78	16.0	0.401
Sine of aspect		– 93.6	96.3	– 10.5	70.20	– 6.6	0.289
Cosine of aspect		– 96.0	68.0	3.9	60.72	15.2	– 0.768

Martinez *et al.* (2006) found *Barbula* sp. and *Tortula revolvens* in two semi-arid gypsum environments of Spain. *T. revolvens* was recorded on gypsiferous soils at only one of the sites in Korubaşı hill and surroundings. Guerra *et al.* (1995) researched on gypsiferous outcrops in SE Spain and two taxa, *Tortula brevissima* and *Syntrichia caninervis* var. *gypsophila* were considered to be rare in the Iberian Peninsula. These species were also gathered from the gypsiferous substrates in the present study. The evaluation of the threat status of each taxon from the studied area was based on Red Data Lists of European Bryophytes (ECCB, 1995). Accordingly, there were three species (*Tortula brevissima*, *T. revolvens* and *Schistidium trichodon*) included in these lists. *T. brevissima* was included in the R (Rare) category, while *T. revolvens* and *S. trichodon* were listed in the threat category K (insufficiently known) for the European catalogue. Maestre *et al.* (2011) studied the ecology and functional roles of BSCs in semi-arid ecosystems of Spain. They found a clear increase in the number and cover of bryophytes, mainly mosses such as *Syntrichia ruralis*, *Pleurochaete squarrosa*, *T. revolvens*, *Didymodon acutus* and *Weissia* sp. These findings were also observed in our study area.

Downing & Selkirk (1993) and Tavili & Jafari (2009) reported that some soil properties such as EC, nutrient status, soil texture, pH, and leaf litter (organic matter) were important in determining bryophyte occurrence. Most of these properties such as soil texture, pH, and SOM content were important attributes affecting moss distribution in the study area and the variation of the studied soils (Table 5) was similar to those reported in the literature (Mulla & McBratney, 2001).

Chamizo *et al.* (2012) found that silt content was higher on the top of the coarse-textured soils, as moss stems and lichen thalli trap airborne silt and clay particles thereby increasing water retention at the surface. The findings of this study showed, interestingly, that the same mosses (*Grimmia trichophylla*, *Orthotrichum affine*, and *Brachythecium mildeanum*) were associated negatively to silt and to WP, indicating that the increase in silt content adversely affected the moss existence through its influence on WP. These mosses were sensitive to wet conditions. No significant relationship was established between FC and any of the studied moss species. Rosentreter *et al.* (2007) reported that the cover of lichens and mosses generally increases with higher clay and silt content and lower sand content. Our results agreed to their findings as soil sand content correlated positively to only the moss *Pleurochaete squarrosa.*

The soil pH related to only one moss (*Grimmia trichophylla*) and EC associated to two moss species (*Orthotrichum affine* and *Brachythecium mildeanum*), suggesting that the studied mosses were more affected by soil physical variables than chemical ones. Bahuguna *et al.* (2012) reported that the soil pH changed between 6.57 ± 0.12 and 7.00 ± 0.10 in India, and Downing & Selkirk (1993) reported that the pH was alkaline and varied between 8.5 and 9.0 underneath mosses in Australia. The weak association between pH and mosses could be attributed to the low variation of the pH (Table 4) in the studied soils.

The SOM content immediately underneath the mosses was considerably high. This high SOM content can provide a favorable condition for mosses. Jafari *et al.* (2004) compared some properties of crusted and uncrusted soils in Iran and reported that the amount of SOM under the mosses and other higher plants was high. The result of the multiple linear regression analysis showed that SOM content was associated with only one of the studied mosses (*Hypnum cupressiforme* var. *lacunosum)* (Table 4) and none of the other studied variables related to this moss presence.

In contrast to our results, Tavili & Jafari (2009) found that altitude was not significantly correlated with the distribution of the species while aspect (northern aspect) showed a strong correlation to mosses in rangelands in the Golestan province of northern Iran. In addition, they also reported that variation in slope steepness had no significant influence on species distribution.

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