

Controlling factors of plant community composition with respect to the slope aspect gradient in the Qilian Mountains

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Abstract. Slope aspect can affect soil temperature and soil type distribution, which, in turn, is likely to influence plant community composition. Three Qilian mountains, located in the northeastern part of the Qinghai–Tibetan Plateau, China, with four distinct slope aspects including south-facing (SF), southwest-facing (SW), northwest-facing (NW), and north-facing (NF) slope aspects, were studied to investigate the impact of slope aspect on plant assemblages. The results indicated that the environmental conditions were favorable under the NF and NW slope aspects as the soil water, soil organic carbon (SOC), and soil total nitrogen (STN) contents were significantly higher, and soil temperature (ST) and soil bulk density (SBD) were significantly lower than under the SF and SW aspects. Under all slope aspects, however, SOC, STN, and soil total phosphate in the top 0.2 m of topsoil accounted for about 60% of its total quantity, to a soil depth of 0.6 m. The plant communities on the SF and SW slopes were found to be primarily composed of *Poa pratensis*, *Potentilla anrisena*, and *Carex aridula*. In contrast, the plant community on the NW slope was mainly composed of *Kobresia humilis*, *Carex crebra*, and *Potentilla bifurca*, while on the NF slope it was mainly composed of *Picea crassifolia*, *Carex scabrostris*, and *Polygonum macrophyllum*. The order of the influence of environmental factors on species distributions was ST > SBD > sand > STN. Results suggest that the slope aspect has an important role in the regulation of the soil environment and plant assemblages and that ST and SBD were the main factors influencing plant community composition. Furthermore, evidence from this study suggests that these mountains will become increasingly vulnerable to global warming. Thus, the plant community composition on these mountains must be monitored continuously in order to allow for strategic adaptive management.

Key words: abiotic factor; mountainous environment; plant species composition; sustainable resources use; topographic factor.

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INTRODUCTION

Plant community composition, a key topic in ecological studies (Zhang et al. 2015), is the result of abiotic (e.g., climate, resource availability, and disturbances) and biotic (e.g., competition, predation, and mutualisms) filters that successively constrain which species are likely to persist at a specific site (Lavorel and Garnier 2002). As such, plant community composition has complex responses to environmental conditions (Kichenin and Freschet 2013, Kumordzi et al. 2015). This can lead to significant uncertainties in the projection of plant assemblages under changing climate and land-use scenarios (Lü et al. 2015). In theory, a plant community has two types of spatial structures: the autogenous structure, which is independent of any environmental variation, and the exogenous structure, which emerges when the species are responding to spatially structured environmental variables (Jones et al. 2008).

Slope aspect can moderate the evolution of local vegetation and ecosystem types through regulation of solar insolation, which directly impacts soil moisture and temperature regimes (Dahlgren et al. 1997, Bale et al. 1998, Sharma et al. 2011, Lozano-García et al. 2016). Dearborn and Danby (2017) showed that plant communities varied more significantly with the slope aspect than they did with elevation. Likewise, Sternberg and Shoshany (2001) found that the vegetation structure within a specific site had changed significantly in the short distance separating the north and south-facing slope aspects, which corresponded to the patterns observed in two other sites with respect to the rainfall gradient. Generally, changes in plant community composition are thought to affect the processes of soil respiration (Johnson et al. 2008), ecosystem structure and function (Hollingsworth et al. 2008), an ecosystem's response to climate change (Shi et al. 2015), and net primary productivity at the ecosystem level due to interactions between plant community composition and environmental drivers (e.g., global warming; Weltzin et al. 2003, Cowles et al. 2016).

Despite the studies mentioned above, detailed evidence-based studies on the influence of topographic factors on plant community composition,

which are especially important for mountainous environments, are only partially available, due in part to the high variability in plant community composition resulting from irregular local topography in mountainous regions (Dearborn and Danby 2017). However, as mountains are considered to be among the ecosystems most threatened by climate change (owing to mountaintop extinction; Bertrand et al. 2011), the lack of detailed knowledge about plant community composition in these ecosystems can impede the interpretation and prediction of plant distributions (Lavorel and Garnier 2002). Fine-scale information on plant community composition, as dependent on the underlying geology and geomorphology of a region (Jones et al. 2008), is needed for effective conservation assessments, long-term planning, and successful vegetation management strategies (Baldeck and Asner 2014).

The Qilian Mountains, located in the northeastern part of the Qinghai–Tibetan Plateau, China, is characterized by a series of parallel mountain chains and broad valleys. The lower section of the mountains has mainly arid geomorphology, with the middle section subject to fluvial geomorphology, and the high section dominated by permafrost geomorphology (Zhao et al. 2012). Most of these mountains have two slope aspects: south-facing (i.e., the sunny slope aspect) and north-facing (i.e., the shady slope aspect). A few of these mountains, however, have four slope aspects, typically including the two aspects mentioned above, as well as the southwest-facing (SW; i.e., semi-sunny slope aspect) and northwest-facing (NW; i.e., the semi-shady slope aspect) slope aspects. Being mainly covered by forest and grassland, these mountains are significant carbon pools in the region (Wagner et al. 2015), although this role is likely influenced by the slope aspect (Qin et al. 2016, Zhu et al. 2017). Therefore, a better understanding of the differences in vegetation characteristics and soil parameters due to differences in the slope aspect is important for sustainable environmental management (Måren et al. 2015), conservation of biodiversity, and restoration of degraded areas (Ahmed et al. 2015), especially in mountainous areas. In this study, the gap mentioned above will be addressed with the hypotheses that plant community composition changes with the slope

aspect and that temperature is the main controlling factor of these changes. Overall, this paper aims to study how the slope aspect influences plant community composition, and which critical factors control plant community composition in this important ecological region.

METHODS

Study area

The Qilian Mountains have a total area of $19.5 \times 10^4 \text{ km}^2$, which is geographically bound within $93.4\text{--}103.4^\circ \text{ E}$ and $35.8\text{--}40.0^\circ \text{ N}$. The elevation in the region ranges from 2000 to 5500 m. The area is characterized by a humid, cold climate, with mean annual precipitation ranging from 250 to 500 mm. The highest air temperature (40°C) occurs in summer in the mountainous plains and downstream area, while the lowest air temperature (-40°C) occurs in winter in the high upper basin area. The specific study sites are located in the core eco-region of the Heihe River basin, in the middle of the Qilian Mountains, with elevations ranging between 2200 and 3000 m, mean annual precipitation of 435 mm, and average annual temperature of 0.5°C .

Experimental design, soil sampling, and vegetation survey

In August and September of 2013 and 2014, three mountains with similar altitude (around 2900 m) and four slope aspects, the south-facing ($0\text{--}90^\circ \text{ SF}$), southwest-facing ($90\text{--}135^\circ \text{ SW}$), northwest-facing ($135\text{--}180^\circ \text{ NW}$), and north-facing ($180\text{--}270^\circ \text{ NF}$) slope aspects, were selected for study, as shown in Fig. 1. The first three slope aspects were dominated by a variety of herbaceous plants, while the latter was dominated by trees (e.g., *Picea crassifolia*).

On the herbaceous slope aspects (SF, SW, and NW), three $10 \times 10 \text{ m}$ plots were arranged at a 10-m spacing along the horizontal contour. On the tree slope aspect (NF), nine $10 \times 10 \text{ m}$ plots were arranged both up and down, from and along the horizontal contour at a 10-m spacing. In each herbaceous plot, three $0.5 \times 0.5 \text{ m}$ quadrants were established in a row and spaced 1 m apart (Fig. 1). In each tree plot, five $1 \times 1 \text{ m}$ quadrants (four in each corner and one in the center) were established, and the number of trees and their diameters at breast height ($\geq 1.3 \text{ m}$) were recorded.

Within each of these quadrants, the percent of vegetation cover and the number of individuals of each plant species were recorded. Soil temperature (ST) at 10 cm belowground was monitored hourly, from 06:00 to 18:00, for three days using an EM50 (Shanghai, China) thermometer by inserting its probes into three random locations within each plot (Li et al. 2011). Soil samples were taken on a sunny day from three herbaceous quadrants and five tree quadrants, to a depth of 0.6 m, which was further divided into four core segments representing 0–0.1 m, 0.1–0.2 m, 0.2–0.4 m, and 0.4–0.6 m in depth.

Soil analysis

Soil water content (SWC) was measured as $\text{SWC} = (\text{mass}_f - \text{mass}_d) / \text{mass}_f \times 100\%$, where mass_f is the fresh mass of soil and mass_d is the mass of oven-dried soil (dried at 105°C for 48 h). Soil bulk density (SBD) was also determined from the undisturbed core segments by dividing the dry soil mass by the unit volume. The soil organic carbon (SOC) content was determined with wet dichromate oxidation using an air-dried homogenized subsample of 0.2 g of soil titrated with FeSO_4 (Nelson and Sommers 1982). Soil pH was determined using a 2.5:1 water-to-air-dried soil ratio and a standard pH meter (Chapman and Pratt 1961). Soil total nitrogen (STN) content was determined by digesting an air-dried homogenized subsample of 0.5 g in sulfuric acid with a $\text{K}_2\text{SO}_4\text{:CuSO}_4\text{:Se}$ catalyst, followed by analysis using a SmartChem 200 discrete analyzer (WestCo Scientific Instruments, Brookfield, Connecticut, USA). Soil total phosphate (STP) content was determined by digesting a homogenized air-dried 0.5-g soil sample with $\text{H}_2\text{SO}_4\text{--HClO}_4$, followed by analysis using the Olsen method (Olsen et al. 1954). Additionally, soil aggregates were dispersed by sodium hexametaphosphate (NaHMP) and placed in an ultrasonic bath for 30 s to determine soil texture. The samples were then analyzed with a laser diffraction technique using a Longbench Mastersizer 2000 (Malvern Instruments, Malvern, UK; Wang et al. 2008).

Statistical analysis

Data analysis was performed using SPSS 16.0 statistical software (SPSS, Chicago, Illinois, USA). ANOVA was used to determine the differences in

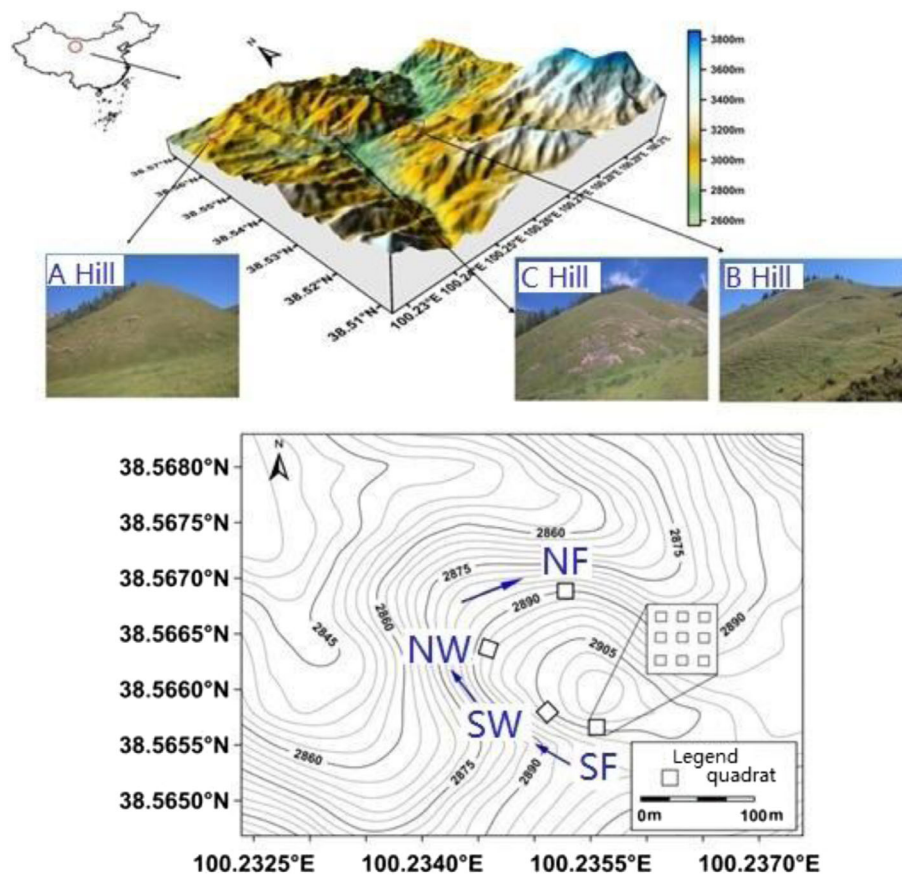


Fig. 1. Location of the three sampled mountains (top), as well as the plot design of the herbaceous plant community (bottom). SF, south-facing slope aspect; SW, southwest-facing slope aspect; NW, northwest-facing slope aspect; NF, north-facing slope aspect.

the factors studied at a significance level of $P < 0.05$. The Importance Value Index (I_v) was used to study the plant species distribution and was calculated as $I_v = (R_c + R_f + R_d)/3$, where R_c is the relative cover, R_f is the relative frequency, and R_d is the relative density for each species. Furthermore, cluster analysis, specifically the K-means method (MacQueen 1967), was used to differentiate the plant communities. Notably, the K-means method was used as it can feasibly divide the body of the original dataset into a predetermined number of clusters (K), with the smallest difference between elements within each cluster and the largest difference between elements of different clusters (Potashev et al. 2014).

Redundancy analysis (RDA), which is a form of direct gradient analysis (Ai et al. 2017), was performed with a subset of environmental

variables to estimate the fraction of the variation of the dependent variables (i.e., plant species composition) that can be attributed to each environmental variable by treating the explanatory environmental variables as regression covariables (Maccherini et al. 2011). Redundancy analysis was performed using the CANOCO5.0 software (Microcomputer Power, Ithaca, New York, USA) to assess the relative influence of abiotic factors on the plant community composition (Yang et al. 2018). The datasets were analyzed before performing RDA with detrended correspondence analyses to confirm that the gradient lengths fit a linear model (ter Braak and Smilauer 2002). The Monte Carlo permutation test was then applied to determine the significances of the eigenvalues of the first and all canonical axes (Yuan 2017, Sun et al. 2018). Conditional effects

(forward selection of environmental variables) were assessed to identify the influence of environmental factors on the vegetation data (ter Braak and Smilauer 2002, Yuan 2017).

RESULTS

Abiotic factors with regard to slope aspect

The mean values of ST under the SF, SW, NW, and NF aspects were estimated to be 16.63°C, 16.02°C, 14.40°C, and 7.43°C, respectively. Among these, the lowest ST was on the NF slope aspect, and it was significantly different from that of the other three aspects. Also, the ST of the NW aspect was found to be significantly lower than that of the SF and SW aspects, albeit with a smaller difference between them. Up to the 0.6 m soil depth, the other abiotic conditions measured for each slope aspect are presented in Fig. 2. With the exception of the soil's mechanical composition, the abiotic conditions under the NF aspect were found to be better than those of the other slope aspects, with the lowest pH (8.04; Fig. 2A) and SBD (0.80 g/cm³; Fig. 2C), and the highest SWC (37.52%; Fig. 2B), SOC (72.50 g/kg; Fig. 2D), STN (3.23 mg/g; Fig. 2E), and STP (0.53 mg/g; Fig. 2F). Moreover, the SWC, SOC, and STN were all significantly higher for the NW aspect, at 26.68%, 33.46 g/kg, and 2.75 mg/g, respectively, than for the SF (21.03%, 16.16 g/kg, and 1.24 mg/g, respectively) and SW (22.34%, 20.63 g/kg, and 1.56 mg/g, respectively) aspects (Fig. 2B, D, E). Furthermore, the SBD was significantly lower for the NW aspect, at 0.93 g/cm³, than it was for the SF (1.14 g/cm³) and SW (1.03 g/cm³) aspects (Fig. 2D). Alternatively, no differences in STP were observed between the NW, SF, and SW aspects (Fig. 2F). In terms of soil texture, the NF aspect had a significantly lower silt content (75.87%; Fig. 2H) but a significantly higher sand content (15.99%; Fig. 2I) than in the other three slope aspects. Moreover, the soil mechanical composition was similar in the SF, SW, and NW aspects.

Some variation in soil properties was observed with regard to soil depth. For soil pH, the present study found that pH was significantly lower in the upper soil layers of all slope aspects, in comparison with the lower layers. As soil depth increased, no significant difference in soil pH was seen among the lower layers in the SF and

SW aspects; however, in the NW and NF aspects, pH significantly increased with soil depth (Fig. 2A). Alternatively, the SBD and SWC on the SF, SW, and NW aspects showed no change as soil depth increased. By contrast, on the NF aspect, the SBD increased with soil depth, from 0.65 g/cm³ in the 0- to 0.1-m layer to 0.95 g/cm³ in the 0.4- to 0.6-m soil layer (Fig. 2C). In contrast, within the NF aspect, the SWC decreased with soil depth, from 45.56% in the 0- to 0.1-m soil layer to 31.12% in the 0.4- to 0.6-m soil layer (Fig. 2B).

Furthermore, the SOC, STN, and STP all decreased with soil depth in all four slope aspects, although in some cases, no significant differences were observed between the different soil layers. Overall, the SOC in the top 0–0.2 m of soil depth accounted for about 67.0%, 64.0%, 62.0%, and 62.0% of the total SOC (to a depth of 0.6 m) in the SF, SW, NW, and NF aspects, respectively. The nutrient content in the 0- to 0.2-m soil layer in the SF, SW, NW, and NF aspects accounted for 62.0%, 60.0%, 63.0%, and 64.0% of STN, respectively, and 59.0%, 59.0%, 58.0%, and 55.0% of STP, respectively (Fig. 2D–F). Although sand decreased with depth for all slope aspects and silt increased with depth on the SW, NW, and NF aspects, no significant trends in the variation of the soil mechanical composition with soil depth were observed (Fig. 2G–I).

Plant community composition with regard to slope aspect

Cluster analysis of the species present on each slope aspect showed that the plant communities on the SF and SW aspects were mainly composed of *Poa pratensis*, *Potentilla anrisena*, *Carex aridula*, and *Stipa grandis*. Alternatively, on the NW aspect, the plant community was primarily composed of *Kobresia humilis*, *Carex crebra*, *Potentilla bifurca*, and *Kobresia capillifolia*. On the NF aspect, the plant community was largely composed of *Picea crassifolia*, *Carex scabrostris*, *Polygonum macrophyllum*, and *Thalictrum baicalense* (Fig. 3). The number of species found on the SF, SW, NW, and NF aspects was 22, 27, 30, and 25, respectively.

The relative influence of abiotic factors on plant community composition

Using the I_v data for each aspect, the interrelationships between species distribution and the

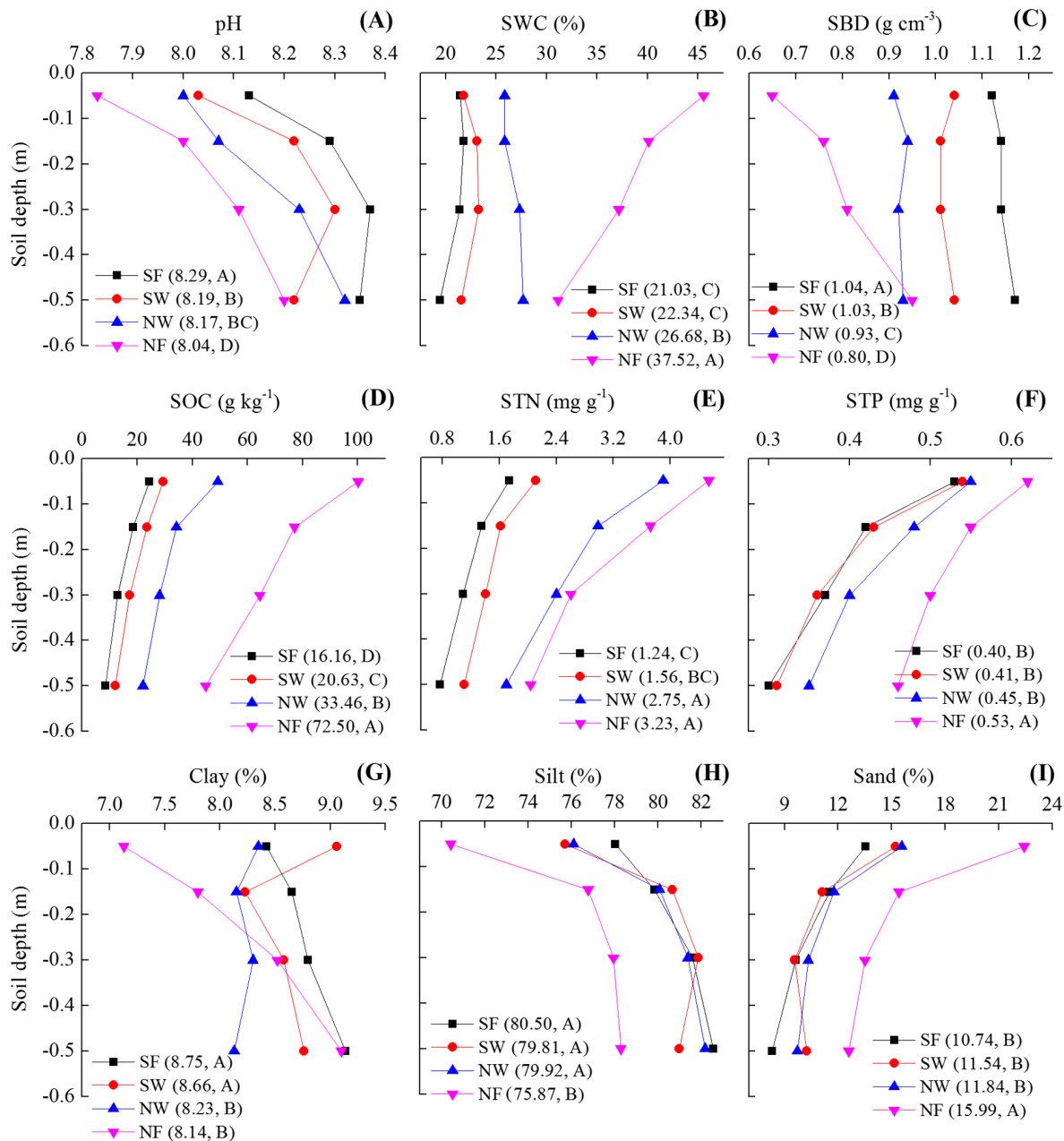


Fig. 2. Soil properties with regard to the four slope aspects and four soil depth ranges. The bracketed values represent the variables' means. Different capital letters indicate significant differences in the variables among slope aspects. SF, south-facing slope aspect; SW, southwest-facing slope aspect; NW, northwest-facing slope aspect; NF, north-facing slope aspect; pH, pH level (A); SWC, soil water content (B); SBD, soil bulk density (C); SOC, soil organic carbon (D); STN, soil total nitrogen (E); STP, soil total phosphate (F); Clay, soil clay (G); Silt, soil silt (H); Sand, soil sand (I).

environmental factors measured were analyzed using the RDA technique (Fig. 4). The RDA results showed that the species distribution in the study region was significantly correlated

with the respective environmental variables. According to the Monte Carlo permutation test, the environmental variables were able to significantly explain the variation with respect to the

first ordination axis ($P = 0.002$), and the total variance ($P = 0.002$). The sum of the eigenvalues of all canonical axes was 0.45, with the first axis being 0.27 and the second axis being 0.12. In terms of the correlation between species (response variables) and environmental factors (explanatory variables), the first axis had a value of 0.92, and the second axis had a value of 0.77. These two axes of the RDA ordination explained approximately 78.71% of the total variation. Specifically, the first axis was positively related to SOC, SWC, STN, STP, and sand, but negatively related to the ST and SBD. The conditional effects indicated that ST, SBD, sand, and STN were significant in the total sum of contributions during the forward selection and these four variables accounted for 82% (calculated by the sum of the four factors divided by the total sum explained by all the environmental factors) of the total variance that could be explained by environmental factors (Table 1).

DISCUSSION

The impact of slope aspect and soil depth on abiotic factors

Slope aspect tends to influence the development of vegetation primarily by affecting the soil moisture and temperature regimes (Dahlgren et al. 1997, Lozano-García et al. 2016). For example, due to the lower ST and higher SWC in the NF aspect, more organic carbon and nitrogen could accumulate in the soil (Gong et al. 2008). In the present study, the trends observed in the abiotic factors (excluding soil mechanical properties) in the SF and NF aspects, and in terms of soil depth (Fig. 2), were similar to other studies (Sidari et al. 2008, Li et al. 2011, Ussiri and Lal 2013, Chen et al. 2016). Although some studies found that pH decreases with increased soil depth (Sonmez et al. 2014), the reverse has also been shown, as was found in this study and forage-based pastures in the subtropical region of southeastern United States (Sigua and Coleman 2010). However, the relationship between the soil mechanical properties and the slope aspect in this region requires further study.

On all slope aspects, the average percentages of SOC, STN, and STP in the top 0.2 m of soil accounted for about 60% of the total SOC, STN, and STP measured from 0 to 0.6 m due to greater

vegetation cover and plant productivity at and near the soil surface (Jing et al. 2014). This result suggests that the topsoil is more sensitive to land-use change and perturbations than the subsoil (Powlson et al. 2011, Ussiri and Lal 2013). Thus, the soil nutrients in the study region would likely be lost if the plant community was degraded by certain changes in land use and management practices (Yimer et al. 2006). Policy-makers should prioritize protecting the NW and NF aspects when creating optimal conservation or restoration plans because their nutrient pools were found to be greater than under the SF and SW aspects.

Factors influencing the plant community composition

Knowledge of the differences in plant communities is essential for long-term management and vegetation planning. Furthermore, the identification of spatial heterogeneity in plant communities is essential when evaluating potential resource problems, and subsequently assessing the value of vegetation for wildlife habitats (Miller 2000). In the present study, herbaceous plants dominated the SF, SW, and NW aspects, while tree species dominated the NF aspect (Fig. 3). This result suggests that the slope aspect has a significant influence on the dominance of certain plant types within plant communities, as was found by others (Armesto and Martínez 1978, Sternberg and Shoshany 2001, Lozano-García et al. 2016). As an outcome of the coordinated evolution of plant species and their respective environments, almost all of the herbaceous plants identified in this study were perennial species, which respond better, in terms of survival/growth rates and high diversity, to different methods of planting, climates, weed invasions, and water table depths (Webb and Erskine 2003, Martínez-Garza et al. 2013). The hardiness of these species also buffers them from increased variation in inter-annual precipitation (Cleland et al. 2013). Additionally, the slope aspects receiving the greatest solar radiation loads are further buffered against the invasion of competitive plant species due to the likelihood of more frequent and severe drought events (Bennie et al. 2006).

Understanding the factors that control plant community compositions allows for improved

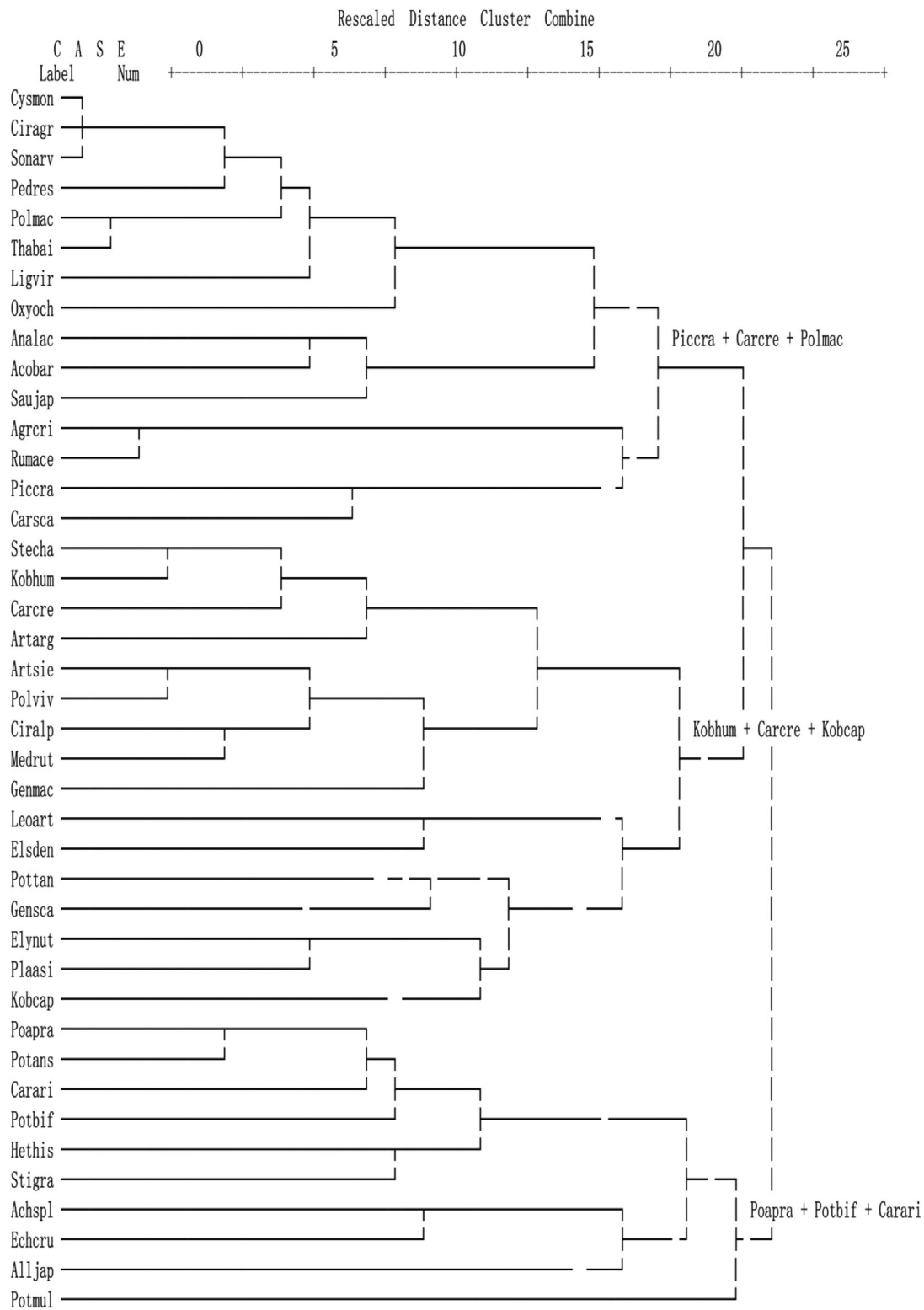


Fig. 3. A dendrogram of plant species (using average linkage between groups) derived from cluster analysis of

Fig. 3. (Continued)

the vegetation data collected within the different slope aspects in the Qilian Mountains. The abbreviations for species are Cysmon, *Cystopteris montana*; Ciragr, *Circaeaster agrestis*; Sonarv, *Sonchus arvensis*; Pedres, *Pedicularis resupinata*; Polmac, *Polygonum macrophyllum*; Thabai, *Thalictrum baicalense*; Ligvir, *Ligularia irgaurea*; Oxyoch, *Oxytropis ochrocephala*; Analac, *Anaphalis lacteal*; Acobar, *Aconitum barbatum*; Saujap, *Saussurea japonica*; Rumace, *Rumex acetosa*; Agrcri, *Agropyron cristatum*; Piccra, *Picea crassifolia*; Carsca, *Carex scabrostris*; Genmac, *Gentiana macrophylla*; Kobhum, *Kobresia humilis*; Carcre, *Carex crebra*; Leoleo, *Leontopodium leontopodioides*; Artsie, *Artemisia sieversiana*; Polviv, *Polygonum viviparum*; Ciralp, *Circaea alpine*; Medrut, *Medicago ruthenica*; Stemed, *Stellaria media*; Artarg, *Artemisia argyi*; Elsdén, *Elsholtzia densa*; Pottan, *Potentilla tanacetifolia*; Gensca, *Gentiana scabra*; Elynut, *Elymus nutans*; Plaasi, *Plantago asiatica*; Kobcap, *Kobresia capillifolia*; Poapra, *Poa pratensis*; Potans, *Potentilla anserine*; Potbif, *Potentilla bifurca*; Carari, *Carex aridula*; Hethis, *Heteropappus hispidus*; Stigra, *Stipa grandis*; Achspl, *Achnatherum splendens*; Echcru, *Echinochloa crusgawi*; Alljap, *Allium japonicum*; Potmul, *Potentilla multifida*; Chegla, *Chenopodium glaucum*.

prediction of the responses of plant communities to natural and anthropogenic environmental change (He et al. 2011). In general, the detected fine-scale spatial variability in plant community composites is more likely related to differences in soil properties along topographic gradients (Jones et al. 2008). In the present study, the RDA showed that differences in plant community composition were largely driven by differences in ST regimes along the slope aspect gradient (Table 1), as was found by others (Gallardo-Cruz and Meave 2009, Yirdaw et al. 2015). Alternatively, in other studies (Li et al. 2011, Omary 2011, Lippok et al. 2014, Yirdaw et al. 2015) it was found that soil moisture was the main aspect-related factor controlling plant community composition. However, since average temperatures in the present study area are only 0.5°C but annual rainfall is 435 mm, the results of this study strongly indicate that ST was the primary limiting factor for plant spread, especially on the NF aspect. Therefore, for the NF aspect, the disturbance resulting from timber harvest could create favorable habitats for the invasion of xeromorphic species (Armesto and Martínez 1978). However, the impact of forest thinning needs further study.

Furthermore, with rising air temperatures the NF aspect's ST may reach beyond a threshold and become more suitable for the competitive plant species currently dominating the SF aspect. Therefore, climate change could ultimately lead to an increase in the NF aspect's species pool, and the composition may start to resemble that of the SF aspect (Dearborn and Danby 2017). Homogenization of the plant community

composition across the slope aspect gradient would likely have widespread implications for the broader ecological functioning of this mountainous ecosystem, as well as for its socioeconomic value (Capon 2005). However, species within a community may respond differently, or even oppositely, to environmental change (Weltzin et al. 2003). Thus, the dynamics of plant community composition on each slope aspect should be carefully studied in order to accurately predict long-term ecosystem response to climate warming (Shi et al. 2015).

The highest plant species richness (based on the number of species, details in *Results: Plant community composition with regard to slope aspect*) in this study was found on the NW aspect. The NW aspect had lower ST than the south-facing aspects, as well as a lower SBD than all slope aspects (details in *Results: Abiotic factors with regard to slope aspect*), suggesting that SBD be considered as a second controlling factor for species distribution in this region. However, the hierarchy of controlling factors is site-specific. For example, in northeastern Siberia the main controlling factor was found to be soil moisture, and the second was pH, while in subarctic Canada the primary and secondary factors were soil temperature and active layer depth, respectively (Bultema 2015). Alternatively, in the San Juan Mountains, USA, the primary factor was pH and the second factor was electrical conductivity for subalpine fen plant community composition, but for alpine fen plant community composition, the primary factor was soil temperature and the second factor was temporal variation in water table depth (Bultema 2015).

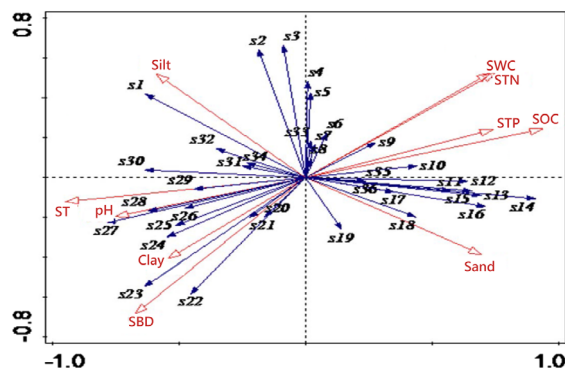


Fig. 4. Redundancy analysis ordination biplot of species and environmental factors. The abbreviations for species are s1, *Carex crebra*; s2, *Stellera chamaejasme*; s3, *Kobresia humilis*; s4, *Leontopodium leontopodioides*; s5, *Artemisia Sieversiana*; s6, *Polygonum viviparum*; s7, *Anaphalis lacteal*; s8, *Gentiana scabra*; s9, *Potentilla tanacetifolia*; s10, *Gentiana macrophylla*; s11, *Thalictrum baicalense*; s12, *Ligularia virgaurea*; s13, *Polygonum macrophyllum*; s14, *Picea crassifolia*; s15, *Carex scabrirostris*; s16, *Pedicularis resupinata*; s17, *Taraxacum mongolicum*; s18, *Rumex acetosa*; s19, *Saussurea japonica*; s20, *Agropyron cristatum*; s21, *Potentilla multifida*; s22, *Potentilla anserine*; s23, *Poa pratensis*; s24, *Heteropappus hispidus*; s25, *Artemisia argyi*; s26, *Potentilla bifurca*; s27, *Carex aridula*; s28, *Allium japonicum*; s29, *Kobresia capillifolia*; s30, *Stipa capillata*; s31, *Achnatherum splendens*; s32, *Echinochloa crusgalli*; s33, *Elymus nutans*; s34, *Oxytropis ochrocephala*; s35, *Pedicularis resupinata*; s36, *Aconitum barbatum*. ST, soil temperature; SWC, soil water content; SOC, soil organic carbon; STN, soil total nitrogen; STP, soil total phosphate; SBD, soil bulk density.

Overall, the present study, along with other research, suggests that the environmental component of spatially explained variation in plant community composition is site-dependent, and this idea is evident at broad scales (in different regions) and fine scales (within one site; Jones et al. 2008). Therefore, permanent plots capturing variation in plant community composition due to major topographic features are needed. These plots should be surveyed and monitored dynamically at each study site (Dearborn and Danby 2017), as long-term experiments can provide invaluable datasets for identifying how species composition changes both spatially and temporally (Cleland et al. 2013, Collins et al. 2016).

Table 1. Conditional effects (forward selection of variables) obtained from the summary of the forward selection for the vegetation data explained by environmental variables in the redundancy analysis.

Variable	Explains (%)	Contribution (%)	F	P
ST	24.6	50.2	11.1	0.002
SBD	8.3	16.9	4.1	0.002
Sand	3.9	8.0	2.0	0.036
STN	3.7	7.6	1.9	0.048
SOC	2.9	5.9	1.5	0.122
STP	1.7	3.4	0.9	0.524
pH	1.8	3.6	0.5	0.498
SWC	1.3	2.6	0.7	0.784
Clay	0.9	1.8	0.4	0.96
Silt	<0.1	<0.1	<0.1	1

Notes: ST, soil temperature; SWC, soil water content; SOC, soil organic carbon; STN, soil total nitrogen; STP, soil total phosphate; SBD, soil bulk density. Bold values mean they were significant in the redundancy analysis.

Once community structure changes, management approaches should also be changed (Miller 2000).

CONCLUSION

In the middle of the Qilian Mountains, the present study shows that the main factors controlling species distribution and composition are soil temperature and soil bulk density. As mountains are more sensitive to environmental change, stabilizing the carbon pool within different slope aspects, especially for the northwest-facing slope aspect, is vital for climate change mitigation and adaptation in this region.

This study suggests that in regions where similar conditions are found, topographic factors should be considered to achieve sustainable use of mountainous resources. However, understanding the response of the plant communities' composition to these factors and variations in their functions and services is essential for identifying which adaptive management measures for social-ecological systems should be adopted.

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