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SHRUB EFFECTS ON HERBACEOUS VEGETATION VARY WITH GROWTH STAGES AND HERB RELATIVE LOCATION

ABSTRACT: In arid and semi-arid ecosystems, shrubs have an important effect on neighboring plants. However, little is known about the interaction of herb growth stages and shrub location on herb performance. We selected *Reaumuria soongorica*, (Pall.) Maxim a shrub dominant in the semiarid region of northwest China, to determine whether (1) shrubs facilitate or have negative effects on neighbouring herbaceous vegetation, and (2) such effects vary with herb growth stage and with shrub orientation relative to herbs. The presence of herbaceous plant species, plant density, plant height, and percent cover were determined along 2 m long transects spreading in four directions from the base of shrub – east (transect E), west (transect W), south (transect S), and north (transect N); this was repeated for three growth stages (in May, June and July). Results indicated that the effects of *R. soongorica* on neighboring herbs in different growth stages were similar. Species number of herb-layer plants tended to increase from beneath the canopy to the opening, but plant density, cover and plant height decreased with distance away from shrub base. The presence of *R. soongorica* had positive effects on density, cover, and plant height, and negative on the number of herbaceous species during the entire growing season. Herbaceous plants growing on transect N under the shrub canopy had significantly higher density and percent cover than those growing in other directions. Biomass of herbs on transect N grown under the shrub canopy was higher than that of herbs on other transects. We concluded that shrub effects on neighbouring herbaceous vegetation were closely related to the shrub orientation relative to the herbs. Therefore, using shrubs as nurse plants for grass-growing must consider the relative placement of shrubs.

KEY WORDS: shrub effects, *Reaumuria soongorica*, herbaceous plants, relative location, growth stage, microhabitats, northwest China

1. INTRODUCTION

In arid and semi-arid ecosystems, shrubs exert important effects on the neighboring plants. Shrubs can influence the growth of other plants, and the structure and function of the herbaceous vegetation in these ecosystems (Armas and Pugnaire 2005, Cavieres and Badano 2009). Research revealed both positive and negative effects of shrubs on neighbouring plants in arid and semiarid ecosystems, the type of outcome commonly related to specific environmental conditions and studied species. Research has focused on shrub effects in relation to soil properties and soil moisture (Rossi and Villagra 2003, Li *et al.* 2010). Shrub effects in different stress gradients and about different shrub species are especially well documented

(Tewksbury and Lloyd 2001, Tirado and Pugnaire 2005, Holzapfel *et al.* 2006). Studies indicated leguminous shrub facilitated herb seedlings establishment and had positive effects on herbaceous vegetation under moderate stress, but tended to be negative during severe droughts (Bertness and Callaway 1994, Jankju, 2013). Other studies focused on the effects of the environment on shrub growth, such as along elevation gradients (Callaway *et al.* 2002), and on shrub morphological characteristics (Callaway 2007).

Among studies addressing specific effects of shrub presence, neighboring plant performance has been evaluated in a given growing season and at random directions away from shrubs; the importance of plant growth stages and of shrub orientation relative to its neighbours have seldom been evaluated. However, shrub effects may not always remain the same across the entire growing season. For example, shrub *Artemisia* has facilitation effects on grass in spring, but neutral effects in summer in arid rangeland (Jankju 2013). Recent studies also indicate that seed deposition and seedling recruitment differ depending on the relative location of shrubs (Li *et al.* 2009). Also plant seedlings have different survival rates when plant at different sides of shrubs (Castro *et al.* 2002). As most studies indicated shrubs could provide a more suitable microhabitat for neighbouring plants, the use of shrubs as nurse plants with its both economic and ecological advantages is widely adopted in reforestation and grass-growing projects (Gómez-Aparicio *et al.* 2004, Jankju, 2013). Therefore, it is important to know how growing stages and directions determine shrub effects on neighbouring plants in studies of shrub multiple effects because it will determine the successful use of nurse shrubs in restoration projects.

Reaumuria soongorica, (Pall.) Maxim a super-xerophytic shrub, is one of the dominant species of desert vegetation in northwestern China. The shrub has a wide ecological distribution in China. It is vital to dune stabilization, soil and water conservation in desert, arid, and semiarid ecosystems, and it plays an important role in community stability and vegetation succession in those areas (Liu *et al.* 1982). Research on *R. soongorica* has focused on ecological, genetic and modular aspects of its population, and its effects on soil properties (Ma and Kong 1998, Guo *et al.* 2009, Liu *et al.* 2010). However, little attention has been paid to how the shrub influenced the growth of surrounding plants.

In this study, *R. soongorica* was selected as a target plant to determine how the presence of shrubs influenced the growth of neighbouring herbaceous plants. The main objectives of our study were to establish whether (1) the shrub *Reaumuria soongorica* has facilitative or negative effects on the neighbouring herbaceous vegetation, (2) the effect changes during different growth periods of the neighbouring herbs, and (3) the shrub effect relates to shrub orientation relative to neighboring plants.

2. MATERIALS AND METHODS

2.1. Study site

This study was conducted at the Gaolan Agriculture and Ecology Research Station of the Cold and Arid Regions Environmental and Engineering Research Institute of the Chinese Academy of Sciences (36°13′N, 103°47′E). The station is located in the transition zone between arid and semiarid regions (Gaolan County, Lanzhou, Gansu Province) at an altitude of approximately 1800 m above sea level. The mean annual rainfall is 263 mm, and approximately 70% of the rainfall occurs between May and September. The mean potential evaporation is 682 mm per year. The mean annual temperature is 8.4°C, with a maximum of 20.7°C in July and a minimum of –9.1°C in January. The prevailing winds during seed dispersal period between late October and early April are north-westerly. The soil is sandy loam of loess origin, classified as the Haplic Orthic Aridisols. The study area is covered by sparse vegetation including drought-resistant shrubs such as *Reaumuria soongorica* (Pall.) Maxim., and *Caragana korshinskii* Kom., and herbaceous plants such as *Artemisia capillaris* Thunb., *Cleistogenes songorica* (Roshev.) Ohwi., *Stipa breviflora* Griseb., *Enneapogon borealis* (Griseb.) Honda, *Artemisia sieversiana* Ehrhart ex Willd, *Peganum multisectum* (Maxim.) Bobr., and *Setaria viridis* (L.) Beauv.

2.2. Methods

In germination stage (early in May), eighteen solitary *R. soongorica* individuals were randomly selected as 'target shrubs' in permanent observation field of the station. Study shrubs were similar in canopy size, at an average of 0.56 m in height and 1.02 m × 1.09 m in crown size, and at least 4 m apart from each other. From the shrub base four 0.2 m wide by 2 m long were directed radially to east, west, south, and north (transects E-N). Each transect was subdivided into ten 0.2 m × 0.2 m quadrats (720 in total) (Fig. 1). Two types of microhabitat were defined in this study: canopy and opening. The 'canopy' habitat was defined as the zone beneath the shrub canopy, and the zone outside the canopy projection was defined as the 'opening'.

Data of herbaceous vegetation properties were collected on species number, plant density (plants number of all species per quadrat. For annual plant, each seedling or plant recorded as an individual; for perennial plant, all stems from one root recorded as an individual), plant height, and percent cover in each quadrat. To determine if the effect of shrubs on herbs differed between different growth periods, we repeated the field survey during three herb growth stages – germination (May), seedling stage (June), and established plants stage (July). Finally, the herbaceous vegetation in each quadrat was cut at ground level, oven-dried at 80°C for 48 h, and weighed to estimate aboveground biomass.

2.3. Data analysis

The mean of four transects of all study shrubs were compared to determine difference of species number, plant density, plant height, percent cover among three growth stages (May, June and July), and the change trends of vegetation properties with distance away from shrub base were showed by fitted curve. To analyze the relationships between species number, plant density, plant height, percent cover and distance away from shrub base in each growth stage, the regression equations for each stage were fitted based on the method of least squares. Differences in species number, plant density, plant height, percent cover, and biomass among transects were determined using ANOVA with LSD post-hoc test. Paired t-tests were used to test differences in species number, plant density, plant height, percent cover, and biomass production between the two defined microhabitat types. All statistical tests were performed using SPSS 13.0.

To test the net effects of shrubs on herbaceous plants, properties of the herbs were compared between different microhabitats with the Relative Interaction Intensity (*RII*) index:

$$RII= (P_{+S}-P_{-S}) / (P_{+S}+P_{-S})$$

where *P* is a measure of the properties (ex. biomass) of herbs beneath the canopy (+*S*) and opening (-*S*) of shrubs. Here, we used data collected from the representative quadrats of the canopy and opening (the nearest

Table 1. Relationships between species number, plant density, cover, plant height and distance away from shrub base during different developmental phases.

Vegetation properties	Stages	Regression equation	R^2	*P*
Species number	May	$y = -0.578x^2 + 1.571x + 1.312$	0.685	0.018
	June	$y = -0.341x^2 + 1.232x + 2.160$	0.857	0.001
	July	$y = -0.436x^2 + 1.140x + 1.517$	0.561	0.050
Plant density	May	$y = -11.182x + 42.6$	0.603	0.008
	June	$y = -9.303x + 51.933$	0.623	0.007
	July	$y = -11.182x + 43.8$	0.713	0.002
Cover	May	$y = -9.804x + 23.379$	0.734	0.002
	June	$y = -9.079x + 28.925$	0.729	0.002
	July	$y = -7.298x + 22.537$	0.793	0.001
Plant height	May	$y = 1.127x^2 - 3.328x + 3.705$	0.593	0.043
	June	$y = 3.220x^2 - 9.059x + 9.327$	0.683	0.018
	July	$y = 4.422x^2 - 11.538x + 13.352$	0.740	0.009

Note: "*y*" is vegetation properties and "*x*" is distance away from shrub base; R^2 is the coefficient of determination.

and furthest quadrat away from shrub base) to calculate the Relative Interaction Intensity index. Values of *RII*> 0 and *RII* <0 indicate net positive and negative effects of shrub on herbs, respectively (Armas *et al*. 2004, Holzapfel *et al*. 2006).

3. RESULTS

3.1. Shrub effects on herbs in different growth stages and microhabitats

In contrast, species number, plant density, and cover in June (seedling stage) were greater than that investigated in May and July, but change trends of vegetation properties during three growth stages showed similar pattern with distance away from shrub base (Fig. 2). Although the increase range was relatively small, species number of herb-layer plants tended to increase from beneath the canopy to the opening (Fig. 2), and the relationship between species number and distance away from shrub base could be fitted with a quadratic equation (P <0.05; Table 1). Moreover, according to the investigated results, some changes were found in species composition between the canopy and the opening. Species under shrub canopy were mainly *A. capillaris* and *A. sieversiana*, but species in opening were mainly *C. songorica* and *A. capillaries,* other species such as *E. borealis, S. breviflora* and *P. multisectum* appeared occasionally beneath the shrub canopy, but appeared more often in the opening.

Although the highest values of density along transects in different growth stages were found at the edge of the shrub canopy (0.6 m away from shrub centre), and the cover peaked under the shrub canopy (Fig. 2). Plant density and cover were both negatively correlated with distance away from shrub base and the relationships were well fitted with linear equation (P <0.01) in different growth stages (Fig. 2; Table 1). Plant height decreased with distance away from shrub base and the changes followed a quadratic equation (P <0.05; Fig. 2; Table 1).

The mean Relative Interaction Intensity (*RII*) of herb properties showed a similar pattern across different growth stages (Fig. 3). Relative Interaction Intensity of species number were <0, but *RII* of density, cover and plant height were > 0 in all growth stages and were larger in May than in June and July (Fig. 3).

3.2. Shrub effects on herbs in different transect directions and microhabitats

Changes in herbaceous vegetation properties in different growth stages exhibited similar trends, therefore, we focus here only on those observed during the established plants stage (July). Species number and plant height were not significantly different (P> 0.05) between canopy and opening in all transect directions, and among the four transect directions (Fig. 4A, D). Herb density was significantly different (P = 0.009) between transect N and the other three transects under canopy, and was significantly different (P = 0.045) between the canopy (79.3 plants · 0.04 m^{-2}) and the opening (26.7 plants · 0.04 m^{-2}) on transect N (Fig. 4A). No significant differences (P> 0.05) of herb density were observed among the other three transects or between the two microhabitats of the other transect directions (Fig. 4B). Herb cover was significantly different among transect directions under the canopy (P = 0.001), but not in the opening (P = 0.719, Fig. 4C). Herb cover differed significantly between canopy and opening only for transects N and W (P = 0.021

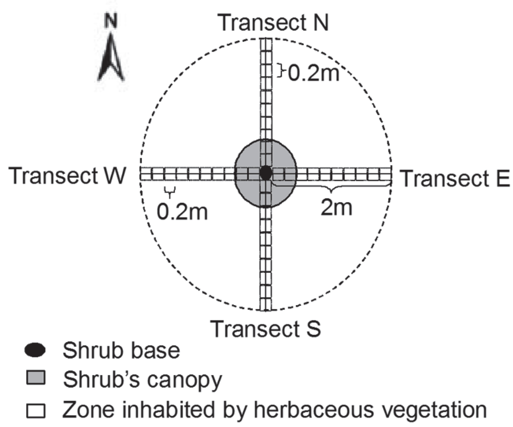

Fig. 1. Position of transects and 0.2 m by 0.2 m microquadrates centered by *Reaumuria soongorica* shrub. Four dotted line strips representing the four transects from shrub base (transects E-N, 0.2 m wide by 2 m long), and each dotted line square represents a quadrat (0.2 m × 0.2 m), ten quadrats in each transect. Grey area represents shrub's canopy, and white area represents zone inhabited by herbaceous vegetation.

Table 2. Effect of Reaumurian *soongorica* shrubs on herb-layer vegetation as expressed by Relative Interaction Intensity (*RII*) along four direction transects centered by the shrub's base. *RII* values were calculated by using average value of all selected shrub specimens data for "canopy" and "opening".

Transect direction	Species number	Density	Cover	Plant height
E	0.1	0.0	0.0	0.3
W	-0.1	0.2	0.6	0.5
S	0.0	0.1	0.0	0.2
N	-0.1	0.5	0.6	0.1

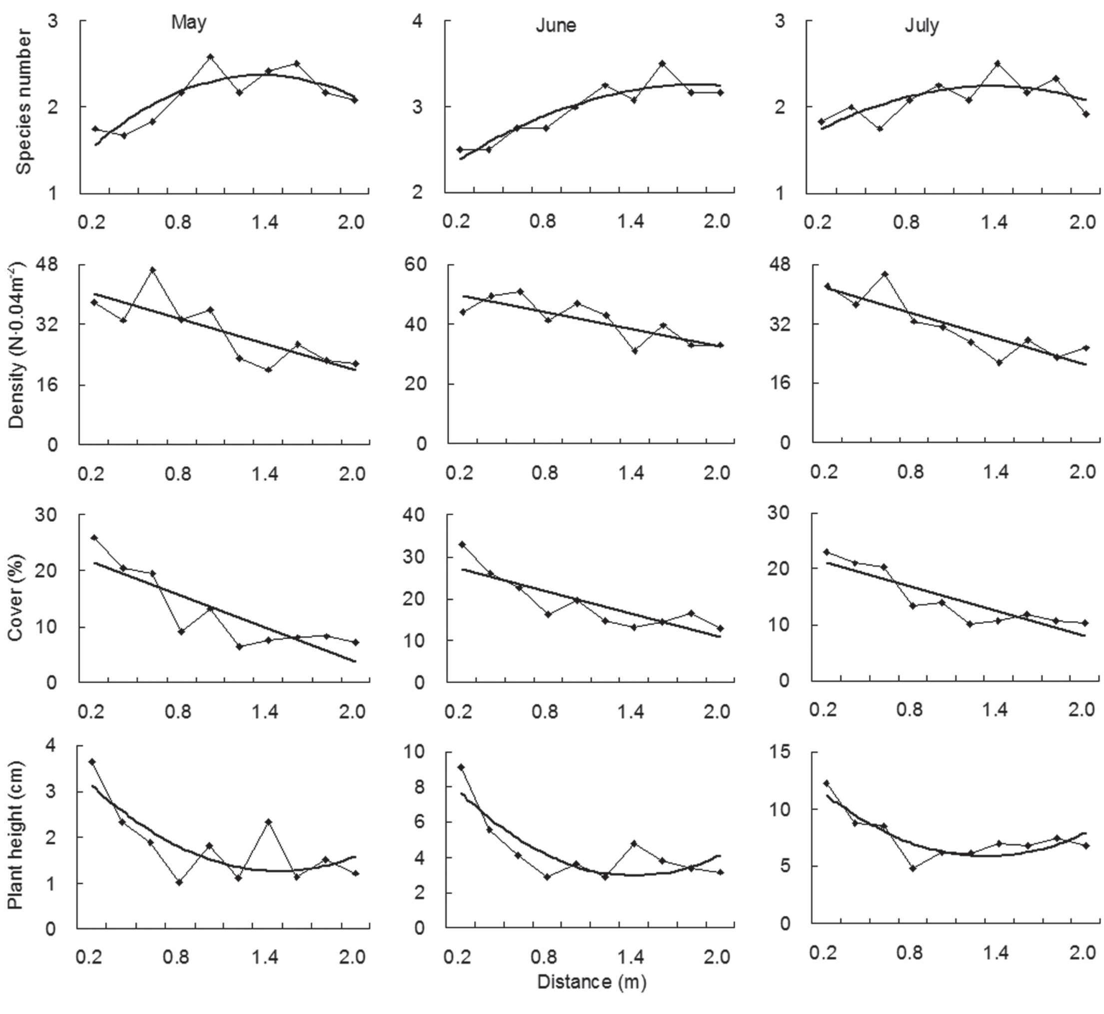

Fig. 2. Changes of species number, plant density, cover, plant height with distance away from shrub base in different developmental phases (the smoothed line is fitted trend line).

and P = 0.005, respectively), but not for E or S (P = 0.755 and P = 0.136 respectively Fig. 4C).

Relative Interaction Intensity of density, cover, and plant height in four transect directions were 0 or > 0. However, *RII* of species number were > 0 only for transect E, but <0 for transects W and N (Table 2).

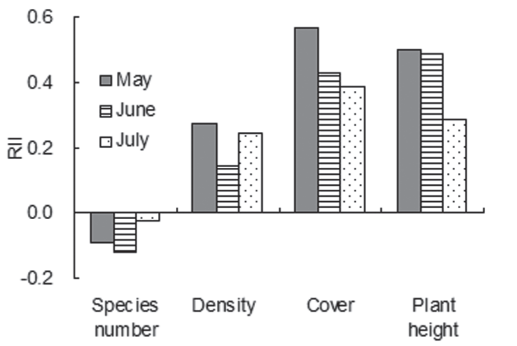

Fig. 3. Effects of *Reaumuria soongorica* shrubs on herb-layer properties as expressed by the Relative Interaction Intensity (*RII*) index in different developmental phases.

3.3. Shrub effects on herb biomass production

Herb-layer plants biomass was significantly greater (P <0.05) under the canopy of shrubs than in the openings across all transect directions (Fig. 5). Biomass of herbs grown under the canopy of transect N was

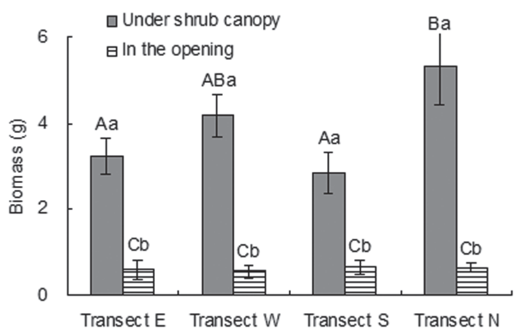

Fig. 5. Biomass of herb-layer plants in four transect directions and in two microhabitats (mean ± SE; different capital letters indicate a significant difference among directions; different lower-case letters indicate significant differences between microhabitats, under shrub canopy and in the opening, P <0.05).

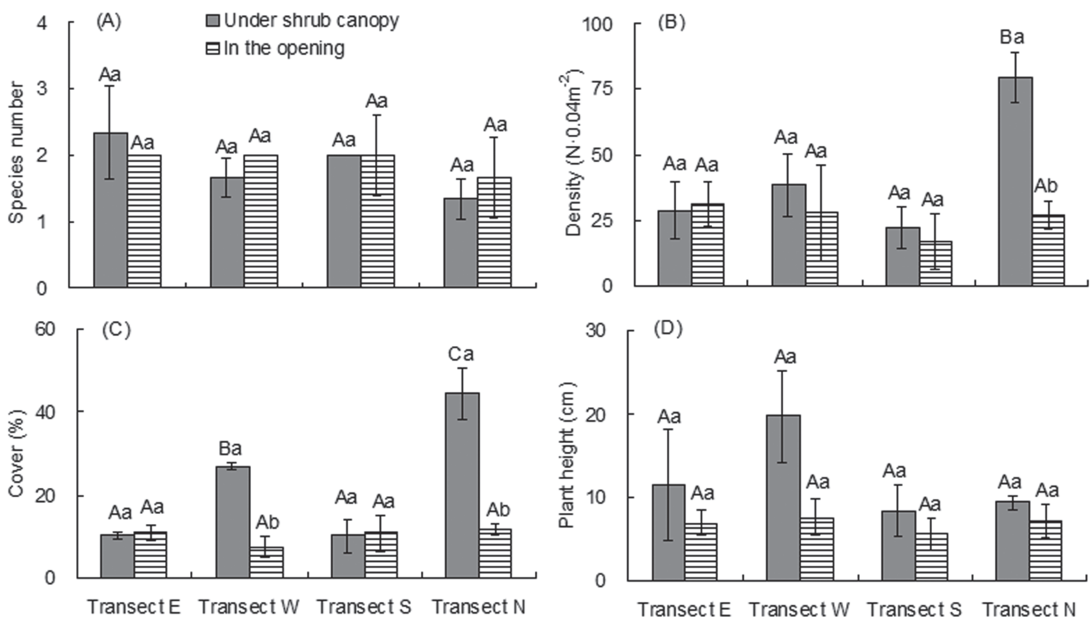

Fig. 4. Species number (A), density (B), cover (C), and plant height (D) of herbaceous plants on different transects during established plants stage (mean ± SE; different capital letters indicate a significant difference among transect directions; different lower-case letters indicate a significant difference between canopy and opening habitat, P <0.05).

significantly higher than that of transects E ($P = 0.039$) and S ($P = 0.020$). However, there were no significant differences in herb biomass under the canopy between transects W and N ($P = 0.215$), and between E, S, and W (E and S: $P = 0.663$, E and W: $P = 0.298$, S and W: $P = 0.156$). Furthermore, no significant differences between transect directions was found with respect to the open microhabitat biomass ($P = 0.977$, Fig. 5).

4. DISCUSSION

In arid and semiarid ecosystems, the presence of shrubs often changes the microhabitat in their vicinity, hence influencing the growth of other species (Flores and Jurado 2003, Espigares *et al.* 2004). The effects of shrubs on neighboring plants are not consistent across different studies. Some results indicate positive effects of shrubs on neighboring herbs (Holzapfel and Mahall 1999); others indicate neutral or negative effects (Weedon and Facelli 2008). Some researchers argued that positive and negative effects of shrubs were balanced at the shrub margin (Li *et al.* 2010). For instance, density and percent cover of herbaceous plants around the shrub *Haloxylon ammodendron* in northwestern China exhibited an increasing trend with the distance away from shrub centre until peaked near the margin of the canopy (Li *et al.* 2010). In the present study, density of herbaceous plants around the shrub *Reaumuria soongorica* also peaked at the edge of the shrub canopy and followed a similar pattern to that observed by Li *et al.* (2010). However, the cover peaked under the shrub canopy and decreased with the distance away from shrub center; the differences between the two studies were probably due to the difference in morphology of the two studied shrubs and variations of fertile island around studied shrub species (Li *et al.* 2007, Pihlgren and Lennartsson 2008).

By using Relative Interaction Intensity (*RII*), we learned that the shrub *R. soongorica* had positive effects on density, cover, plant height, and biomass of the neighboring herbaceous vegetation, but negative effects on the number of herb species (Fig. 3). Therefore, shrub effects on herbs were positive or negative depending on herb trait considered. According to regression analysis, plant density and cover were correlated negatively with distance away from shrub base in significant linear relationship (P <0.01), species number and plant height also changed with distance away from shrub base, but the relationships just fitted with quadratic equation at 95% level significance (P <0.05). Therefore, shrubs have much more significant effects on plant density and cover than on another two properties. This may be related to shrub effects on plant seed deposition (Li *et al.* 2009).

In our study, herb growth changed from the canopy to the opening in a similar pattern in different growth stages. Moreover, the mean *RII* values calculated for different vegetation parameters during different growth stages exhibited a similar pattern, but *RII* of density, cover, and plant height were above zero and were larger in May than in June and July. This indicated that shrub effects on density, cover, and plant height were positive but gradually decreasing as growing stages advanced. This may be due to the sensitivity of seed germination and seedling establishment stages to the variation in microhabitat conditions (Colbach *et al.* 2002, Jarvis and Moore 2008, Thompson and Ooi 2010). In addition, competition for resources among species may increase with plant growth.

The presence of shrubs influenced population dynamics and growth properties of other species in the vicinity, but the effect was probably moderated by the relative shrub location. Thus, pine seedlings had higher survival rates when planted to the north of shrubs than in the other directions (Castro *et al.* 2002). Results of Li and his colleagues (2007, 2009) further suggested that seed deposition and seedling emergence were closely related to the direction of shrubs and the prevailing wind. Our results support the results of these previous studies (Castro *et al.* 2002, Li *et al.* 2007) and the differences in the performance of herbs in our study were associated with the relative shrub location. This may be due to the fact that environmental conditions, such as soil and air temperature, and soil moisture, vary with microhabitat resulting from shrub direction (Ko and Reich 1993, Haworth and McPherson 1995, Castro *et al.* 2002).

Our results indicated a facilitative effect of shrub canopy on the herbaceous vegetation located on the north-oriented transect probably due to more shade, lower temperature, lower radiation, and higher soil moisture, as also noted in other studies (Hastwell and Facelli 2003, Jankju 2013). Moreover, the prevailing wind in our study area also influenced nutrient and dust particles trapped by the shrubs, causing differences in soil fertility in microhabitats of the different transect directions (Su *et al*. 2004). Therefore, we demonstrated that shrub orientation relative to other plants should be considered when using shrubs as nurse plants for grass-growing. In our study area, when *R. soongorica* was used as a nurse plant in vegetation restoration, associated herbaceous species performed significantly better when located in the northern directions of shrubs.

5. CONCLUSIONS

This study showed that the shrub *R. soongorica* influenced growth and performance of neighbouring herbaceous vegetation, confirming results of other studies with different species. This effect of *R. soongorica* on herbaceous plants was similar in different herb growth stages. Shrub effects on herbs were positive or negative, depending on the herb trait considered. Shrubs have much more significant effects on plant density and cover than on other properties. Plant density and cover were negatively correlated with distance away from shrub base and the relationships were well fitted with linear equation. Herbs located north of shrub and growing under the canopy of shrubs grew better than those located in other directions. In addition, biomass production of herb-layer vegetation grown under the canopy on transects N was higher than that in other directions. We conclude that shrub effects on herbaceous vegetation are closely related to relative location of plant individuals under shrubs. Therefore, the practice of using shrubs as nurse plants for grass-growing will benefit from considering the relative location of shrubs. In our study, growing north of *R. soongorica* was more suitable for herbaceous species than growing in other geographical directions.

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