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Quantifying the effect of shading and watering on seed germination in translocated forest topsoil at a subtropical karst of China

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ABSTRACT

Soil translocation is recognized as a promising method to recover degraded ecosystems and save regionally threatened species, however, the diversity and density of woody species, and the similarity of germinated seedlings between translocated site and donor forest are always low, and few studies have paid attention to the manageable environmental factors for seed germination when forest topsoil exposed to strong light condition. In this study, we tested how shading treatment (ST) and watering treatments (WT) affect the germination of species in translocated forest topsoil and whether different life forms respond differently to different ST and WT following soil translocation. We found that the richness of shrub species had a positive linear relationship with WT, and increased by 0.8 species when additional 10 L m^{-2} water was added. The richness of trees species was positively linearly correlated with ST and increased by 0.5 species when 10 units of shade degrees was increased. The effect of ST on richness was greatest for total species, followed by herb and tree species, while the effect of WT affected these in the order total > herb > shrub species. The densities of shrub and tree species had a positive linear relationship with ST and increased by 1.0 and 1.2 seedlings m^{-2} when 10 units of shade degrees were increased respectively. Whereas, the densities of total species, herb species, and liana species had a parabolic relation with ST, reaching maximum densities of 79.8, 39.8, and 5.3 seedlings m^{-2} at shade degrees of 70%, 45%, and 27.5%, respectively. Moreover, the similarity between germinated communities and donor forest had positive linear relationship with ST and WT, except for herb species. Therefore, in theory, ST and WT significantly improved the diversity, density, and similarity of woody seedlings in translocated forest soil, but the density of herb and liana species decreased respectively when shade degrees exceeded 45% and 27.5% respectively. In practice, putting soil under moderate or heavy shade (shade degrees range from 45% to 70%) is a promising method to duplicate a diverse and similar forest if translocation process coincides with the rainy season. This finding can be incorporated into the practice and management of natural forest restoration and accelerate the early stage of forest restoration and succession.

1. Introduction

Deforestation and degradation are threatening biodiversity worldwide and may be related to global climate warming (Lewis et al., 2015; Foley et al., 2005). Although preventing the further destruction of ecosystems is a key element of efforts to improve this situation, restoration of formerly forested land is increasingly recognized as a parallel strategy that can have significant benefits (Chazdon, 2008; Lugo, 2015). In past decades, many traditional strategies, including preservation to allow natural regeneration and afforestation initiatives, among others, have been employed (Sizemskaya et al., 2001, Houghton et al., 2015; Martinez-Ramos et al., 2016) and have achieved some success in warmer and wetter regions (Tong et al., 2017; Crouzeilles et al., 2017), but most strategies have resulted in highly variable recovery rates and single-species communities (Suding and Hobbs, 2009; Seabrook et al., 2011; Trac et al., 2007; Uchida et al., 2005; Cao 2011). Hence, new methods are needed.

The soil seed bank plays an important role in maintaining the ecological and genetic diversity of communities and may thus be an important component of community restoration and succession (Thompson and Grime, 1979, Gonzalez-Alday et al., 2009). Soil translocation carries many seeds and vegetative propagates that possess

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regionally specific species composition and hereditary characters, which should effectively sustain the diversity and stability of native species (Jalili et al., 2003). In recent years, the technique has been recognized as a promising method of restoring previously mined areas (Parrotta and Knowles, 1999; 2001; Koch 2007), roadsides (Skrindo and Halvorsen, 2008; Tormo et al., 2007), grasslands (Vecrin and Muller, 2003; Hosogi and Kameyama, 2004), and other areas (Wang et al., 2016; Shen et al., 2013). However, the diversity and density of woody plant species are always low, possibly because either woody plant seeds from donor forest cannot germinate at receiving sites or herb persistent soil seed bank from donor forest vegetation germinate wildly at receiving sites when forest topsoil are exposed to a new and open environment (Warr et al., 1993; Pywell et al., 2002; Williams et al., 2008; Fowler et al., 2015; Chenot et al., 2017), which ultimately leads to low similarity of germinated seedlings between translocated site and donor forest (Hopfensperger, 2007; Bossuyt and Honnay, 2008). Many studies have inferred that these results may be attributable to spatially structured deposition patterns of soil seed bank (Plue et al., 2010), short-lived seeds (Bossuyt and Honnay, 2008), ephemeral seed banks (Hopfensperger, 2007), seed predation (Garcia-Orth and Martinez-Ramos, 2008), soil inoculation and seed dormancy (Wubs et al., 2016), but none of them addressed the environmental conditions that were present during soil translocation.

The soil translocation process generally involves stripping topsoil from a donor forest and using it to replace topsoil at degraded site (Pywell et al., 2002; Warr et al., 1993). Such sites are typically very bright, open (not forested) areas with high water evaporation conditions that are very different from those in the donor forest (Parrotta and Knowles, 1999; Hu, et al., 2019). This may have a huge impact on seed germination, especially for tree and shrub species that require low levels of light (Baskin and Baskin, 2014). Thus, controlling the germination environments of translocated forest topsoil in a state that is as similar as possible to donor forest sites may favor seed germination and thus the success of such project.

The environment assembly model considered community was structured primarily by species' physiological and demographic responses to the physical environment (Jackson and Overpeck, 2000; Post, 2013). It is predicated on all species having finite environmental requirements or tolerances, especially regarding light and water, which imposes strong filters on community membership (Jackson and Blois, 2015). The effect of light on seed germination is mainly as a signal stimulus to break seed dormancy, rather than as a source of energy directly involved in the seed germination process (Bewley and Black 1982), and water may be the main factor influencing the richness and density of seedlings in arid, semi-arid, and semi-humid areas (Ortiz et al., 2019; Muller et al., 2019, Hu et al., 2019). Other quantitative studies on the effects of shading and watering on seed germination, seedling growth and development are mainly focused on individual species or completed in the laboratory (Kyereh et al., 1999; Ruano et al., 2009; Su et al., 2010; Zhang et al., 2012), which is quite different from field experiments. However, the topic, how the manageable environmental factors affect the germination of species in translocated forest soil at a subtropical karst of China, has not been confirmed.

In this study, we employed multiple regressions to quantify the effects of shading treatment (ST) and watering treatment (WT) on germination in translocated forest topsoil. Aiming at exploring how ST and WT affect the germination of species and whether different life forms respond differently to different ST and WT. We expect to provide quantitative data supporting restoration of degraded ecosystem and render some management implications for natural forest succession.

2. Materials and methods

2.1. Study site

This study was conducted in Jianshui County, Yunnan Province, southwest China. The mean annual precipitation is 785.1 mm, most of it falling between May and October (rainy season). The mean annual evaporation capacity (about 2000 mm) is considerably greater than the precipitation level, typical of semi-humid and semi-arid regions (Jianshui Forestry Bureau, 2005–2015). The donor site consisted of a residual secondary sclerophyllous-evergreen broadleaved forest (SSBF), characterized by small human disturbances and high plant diversity. *Quercus baronii* dominates the forest, and limestone rocks of different size are exposed at the soil surface. The receiving site was ca. 5 km away from the donor site that separated by agricultural and deforested land, a long enough distance to prevent natural seed dispersal of donor forest. It has the same limestone base and similar elevation but more exposed rocks than the donor site. The vegetation is dominated by annual and perennial herbs, such as, *Heteropogon contortus*, *Arthraxon hispidus,* and *Themeda hookeri*. Although it has been undergoing natural regeneration for many years, no woody species are present because of the lack of seed banks of woody species.

2.2. Experimental design and receiving site preparation

The quadratic saturation D-optimum design model was used widely in agricultural fertilization tests (Liu, 2011; Olaf and Martin, 1992; Dette, 1990). Here, we applied the experimental design of two-factor (ST and WT) four-level (0, light, moderate and severe) 9 treatments to the translocated forest topsoil. We designed without ST (S0) as ca. 0% of shade degrees, light ST (S1) as ca. 30% of shade degrees, moderate ST (S2) as ca. 50% of shade degrees, and severe ST (S3) as ca. 70% of shade degrees. Black shading nets were carefully selected and tested by measuring photosynthetically active radiation (PAR) (Skye Instruments Ltd, Powys, UK) to ensure a PAR within a range of ± 5%. Moreover, we defined the difference of soil water content between in donor forest and in receiving site as the moderate WT (W2), light WT (W1) as ca. 0.5 time of W2, severe WT (W3) as ca. 1.5 times % of W2, and without watering (W0). These treatments were intended to represent forest canopy, forest edge, forest gap, and forest understory, respectively. The final treatment combinations are given in Table 1.

Each treatment included 10 replicates, thus 90 field plots were established in an approximately 5 ha at the receiving site. This site was separated into five 50 m × 50 m areas, and then each area was divided into one hundred 5 m × 5 m plots. Eighteen plots were randomly selected as treatment plots to establish two duplicates of the nine treatments. For each selected plot, vegetation and 5–10 cm topsoil were removed prior to soil translocation to eliminate the effect of the propagule bank at the receiving site. Two 2 m × 4 m areas were established as an experimental area, and the residual area was used as an aisle for experimental observation and data recording. For ST plots, a steel-frame structure (5 m × 5 m × 2.5 m) was built to fix the shading shed. The design and processes are shown in Fig. 1.

Table 1
Experimental treatments and environmental conditions in different treatments.

Treatments	ST	WT	SD (%)	WQ (L m^{-2})	PAR
S0W0	0	0	0	0	187.8 ± 1.2
S0W2	0	2	0	20	187.8 ± 1.2
S1W1	1	1	29 ± 4	10	133.8 ± 1.0
S1W2	1	2	29 ± 4	20	133.8 ± 1.0
S2W0	2	0	47 ± 5	0	100.1 ± 1.2
S2W1	2	1	47 ± 5	10	100.1 ± 1.2
S2W2	2	2	47 ± 5	20	100.1 ± 1.2
S2W3	2	3	47 ± 5	30	100.1 ± 1.2
S3W2	3	2	66 ± 6	20	64.1 ± 1.2

Note: ST (shading treatment); WT (watering treatment); SD (shade degrees); WQ (water quantity); PAR (photosynthetically active radiation).

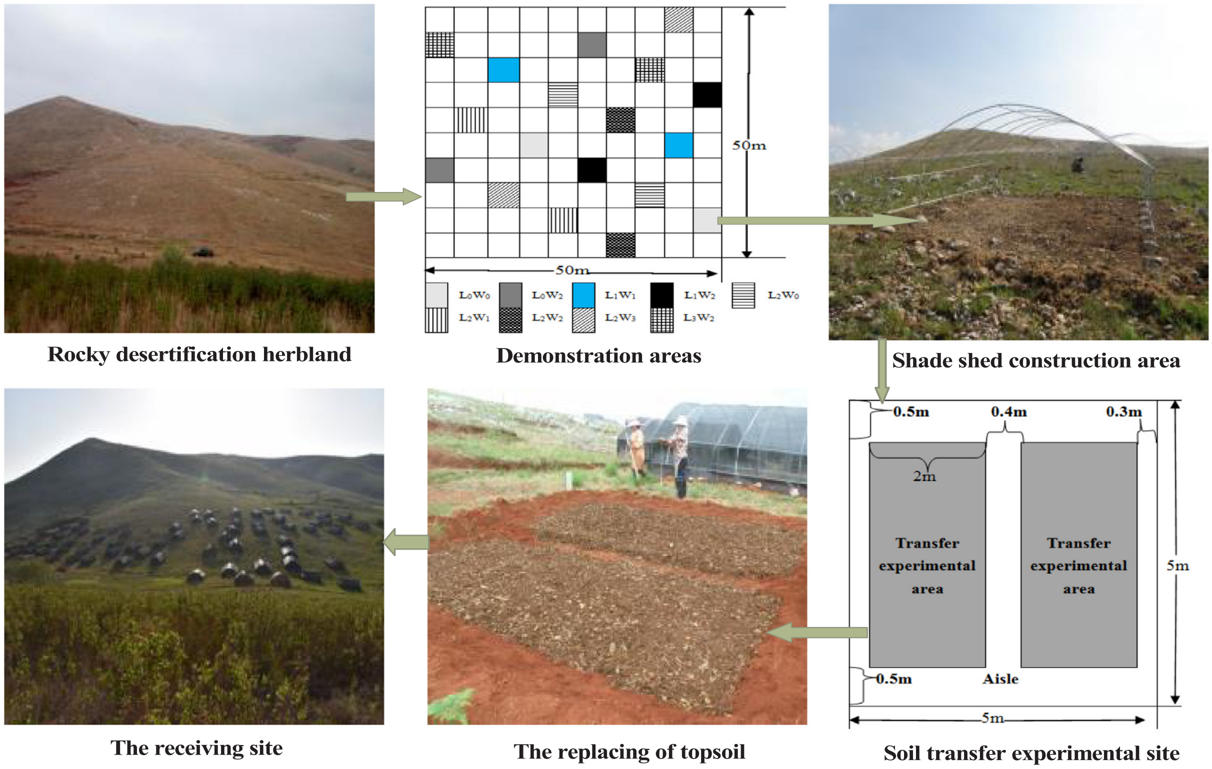

Fig. 1. Schematic of soil translocation process.

2.3. Vegetation survey and topsoil sampling of donor site

A vegetation survey was conducted at the donor site, where 20 m × 20 m quadrats (n = 15 replicates) along an elevation gradient were established to check overstory woody species and 2 m × 2 m quadrats (n = 60 replicates) were used to check understory species. A total of 45 plant species, belonging to 27 families and 41 genera, were recorded, with 12, 9, 17, and 7 species of tree, shrub, herb, and liana, respectively. Although the total average plant density was only 12.0 seedlings m^{-2}, the density of tree, shrub, herb, and liana species reached 4.3, 4.9, 1.8, and 1.0 seedlings/m^2, respectively.

We manually collected topsoil from 1 m × 1 m quadrats (2 within a 10 m × 10 m plot) down to 10 cm depth in May 2017. The total collection area only accounted for 2% of the ground area that had minimal damage (Douterlungne et al., 2018). In total, we collected one thousand and five hundreds quadrats, approximately 65,000 kg of topsoil along the vegetation survey route. Following collection, topsoil was stored in plastic bags, weighed, and transported to the receiving site.

2.4. Soil re-spreading, experimental management, and data recording

Soil translocation, which included stripping, transporting, homogenizing, and re-spreading the topsoil, had to be implemented immediately after collection, before the onset of the rainy season in this region in June. Topsoil in each bag was poured out manually at the top of mound at a prepared plastic cloth (10 m × 10 m) nearby the experimental site randomly to try to homogenize forest topsoil (minimize the difference of soil origin). Based on the total amount of topsoil collected, we set an average soil weight (720 kg) for each of the 90 plots.

Following soil translocation, 70 plots were covered by different shade nets, and the other 20 plots were open according to the experimental design. Soil water content in donor forest and in receiving site was monitored every month from May to October. The watering quantity for each treatment was calculated following the design (Table 1), and then water was spread evenly in each plot (16 m^2). Totally, we total watered 160 L, 320 L, and 480 L in W1, W2, and W3, respectively, and the water quantity is about 10 L, 20 L and 30 L per m^2 (Table 1).

One 1 m × 1 m quadrat was set in each plot to monitor seed germination once every month. Seedlings were identified by relevant experts. Species richness and abundance of different life forms were recorded and densities of different life forms were calculated. Meanwhile, PAR was measured using a 400–700 nm quantum sensor (Skye Instruments Ltd, Powys, UK) between 12:00–14:00 on cloud-free days once a month and each time twenty repetitions (Table 1).

Very few specie have persistent soil seed banks (time persisted in soil ≥ 1 germination season) in this region (Shen et al., 2014). The growing season normally ended at November in the study area. Our monitoring data at November also showed a decrease trend of richness and density. Thus, we ended our census at December.

2.5. Statistical analyses

All analyses were conducted in R, and the Aov and TukeyHSD function were used to compare species density by month for each treatment and by treatment in the end stage of germination (November). The dissimilarity coefficient between germinated seedlings in different treatments and donor forest were calculated using the Vegdist function with Bray-Curtis methods and dissimilarity coefficient were converted into similarities to make the comparison easier to understand. Multiple regressions were established to fit the effects of ST and ST on species richness, species density, and similarity coefficient using stepwise regression method. Additionally, normal distribution and homogeneity of variances were examined by the Shapiro-Wilk test and Levene's test before the above analysis was conducted.

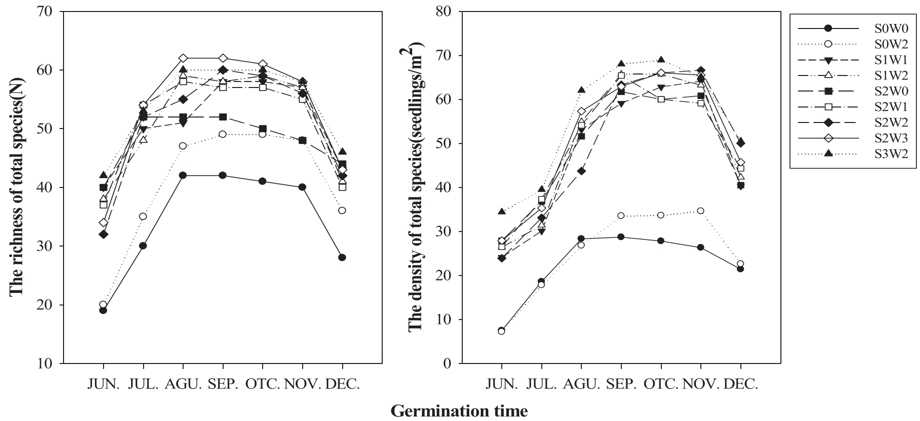

Fig. 2. Richness and density of total species under different shading and watering combinations.

3. Results

3.1. Germination dynamics and the richness and density at the end stage of germination

Overall, the richness and density of germinated seedlings significantly increased from June to September. The increase remained up to November, and then declined markedly for all treatments. Thus we defined the germination period as extending from June to November, where November was the end stage of germination during soil translocation (Fig. 2).

In the end stage of germination (in November), a large difference was identified between ST and WT and non-treatment in terms of the richness and density of total species and different life forms. Overall, herb species accounted for about half of all species in both richness and density for each treatment. Additionally, the species composition ratio without WT and ST (S0W0) presented herb > liana > shrub > tree species, and it shifted to herb > shrub > tree > liana species or herb > tree > shrub > liana species for treatments with ST and WT (Table 2).

3.2. Effects of ST and WT on richness of total species and different life forms

We took the richness recorded in the end stage of germination to represent seed germination for all treatments (Table 2) and the multiple regressions was applied to assess the effects of ST and WT on species richness. Overall, richness had a positive linear relationship with ST and WT, except for liana species, which was no significant difference with ST and WT (Fig. 3e). The richness of total, herb, shrub, and tree species reached 42.8, 20.1, 9.5, and 6.7 species, respectively, even without ST or/and WT (Fig. 3). Herb species richness had a positive linear relationship with ST and WT, and the richness increased by 0.8 and 2.8 species respectively when additional 10 shade degrees and 10 L m^{-2} water were added, respectively (Fig. 3b). The richness of shrub species had a positive linear relationship with WT and the richness increased by 0.5 species when additional 10 L m^{-2} water were added (Fig. 3c). And the richness of tree species had a linear relationship with ST and improved 0.7 species when 10 shade degrees were added (Fig. 3d).

3.3. Effects of ST and WT on density of total species and different life forms

We took the density recorded at the end stage of germination to represent seedling density for all treatments (Table 2), and the multiple linear regressions was used to fit the effects of ST and WT on the densities of total species and different life forms. Species density was affected significantly only by ST. The densities of total, herb, shrub, tree, and liana species reached 30.8, 19.6, 5.7, 3.3, and 3.7 seedlings m^{-2}, respectively, even without ST. The densities of shrub and tree species both displayed positive linear relationships with ST (Fig. 4c, 4d), and increased by 1.0 and 1.2 seedlings m^{-2} when shade degrees was increased by 10 units. However, the densities of total, herb, and liana species had parabolic relationships with ST, with maximum densities of 79.8, 39.8, and 5.3 seedlings m^{-2} at shade degrees of 70%, 45%, and 27.5%, respectively (Fig. 4).

3.4. Effect of ST and WT on similarity between germinated seedlings and donor forest vegetation

We calculated dissimilarities using the Bray-Curtis method, converted them into similarities, and then assessed the effects of ST and WT on similarity between germinated seedlings at the receiving site and the donor forest vegetation using multiple linear regressions. Overall, similarity increased with ST and WT increasing for total species and different life forms, except for herb species (Fig. 5). The similarities in

Table 2
Species richness (including species composition ratio) and density of total and different life forms in different treatments at the end stage of germination.

Life forms	Species richness (species composition ratio): a(b)					Species density (seedlings m^{-2})				
Treatment	Total	Herb	Shrub	Tree	Liana	Total	Herb	Shrub	Tree	Liana
S0W0	40	19 (47.5)	8 (20.0)	5(12.5)	8(20.0)	25.3 ± 6.8	16.5 ± 4.9	3.8 ± 3.1	1.5 ± 0.8	3.9 ± 1.9
S0W2	48	25 (52.1)	10(20.8)	7(14.6)	6(12.5)	34.6 ± 8.2	22.3 ± 5.6	6.4 ± 5.6	3.1 ± 1.4	3.4 ± 2.0
S1W1	57	27 (47.4)	10(17.5)	12(21.1)	8(14.0)	64.1 ± 9.1	39.8 ± 7.3	8.4 ± 4.7	9.2 ± 6.1	6.7 ± 2.7
S1W2	57	30 (52.6)	11(19.3)	9(15.8)	7(12.3)	63.2 ± 6.1	37.1 ± 5.9	10.9 ± 3	9.6 ± 4.1	5.6 ± 2.3
S2W0	48	23 (47.9)	10(20.8)	9(18.8)	6(12.5)	60.8 ± 9.2	39.6 ± 5.1	9.0 ± 4.3	8.2 ± 5.1	4.8 ± 2.7
S2W1	55	29 (52.7)	10(18.2)	9(16.4)	7(12.7)	59.1 ± 9.1	36.8 ± 9.7	10.3 ± 6	6.7 ± 2.3	5.9 ± 2.0
S2W2	56	28 (50.0)	11(19.6)	10(17.9)	7(12.8)	66.6 ± 9.5	42.2 ± 9.8	11.9 ± 5	7.3 ± 5.2	5.2 ± 1.5
S2W3	58	32 (55.2)	11(19.0)	10(17.2)	5(8.6)	65.5 ± 7.7	42.6 ± 9.6	9.5 ± 4.7	9.1 ± 5.9	4.3 ± 1.4
S3W2	58	30 (51.7)	10(17.2)	11(19.0)	7(12.1)	65.1 ± 6.2	38.2 ± 8.1	11.3 ± 7	11 ± 5.8	4.5 ± 1.8

Note: Data format a (b): a is species richness (N), b is species composition ratio (%); Species composition ratios were calculated as the number of herb, shrub, tree, and liana species divided by the number of total species.

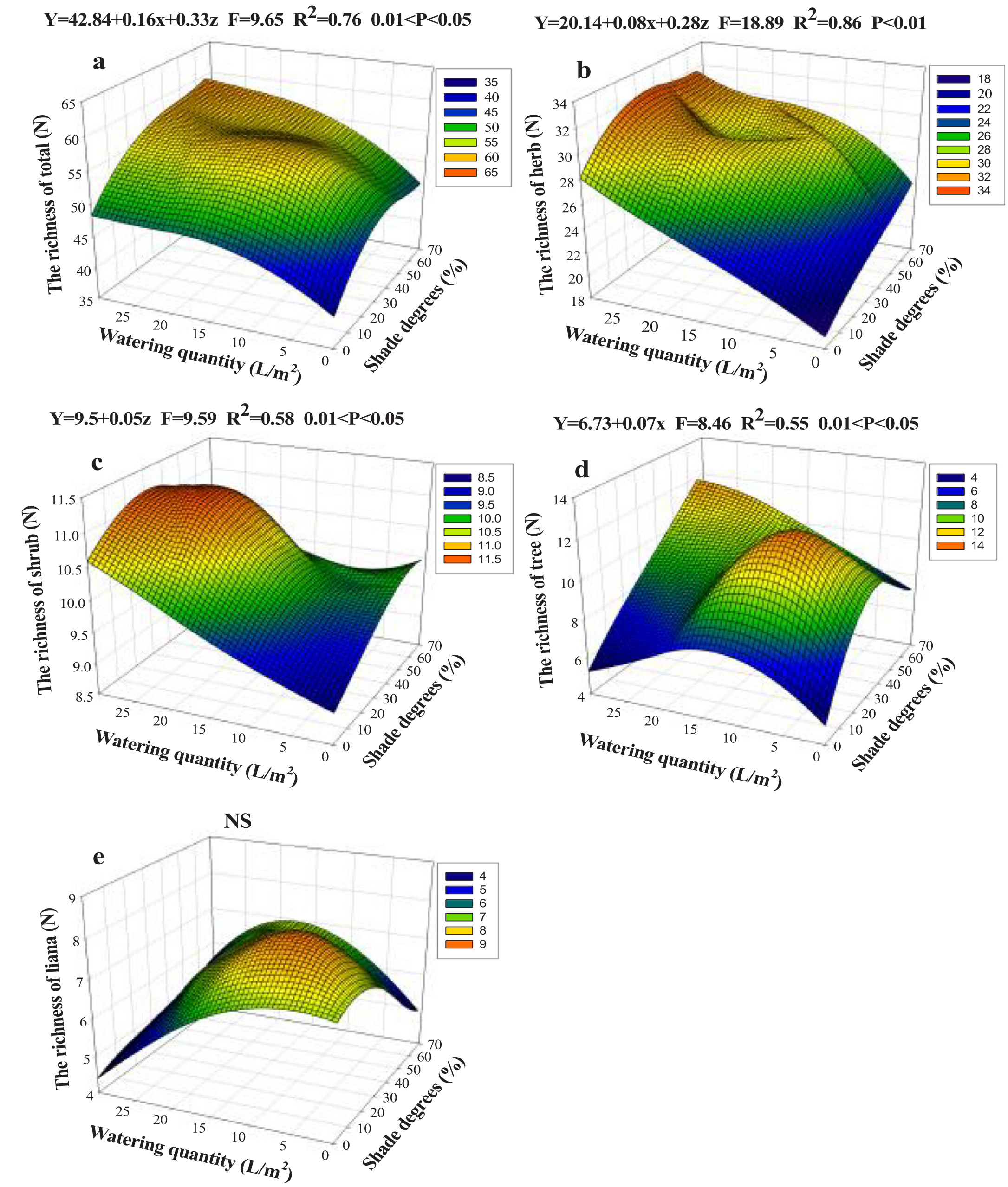

Fig. 3. Effects of shading and watering on total richness and the richness of different life forms that germinated after forest topsoil translocation Note: In the fitting equation, x is degree of shade, z is water quantity, and Y is species richness; NS: not significant.

terms of total, shrub, tree, and liana species were only 0.3, 0.48, 0.3, and 0.38 respectively when there were no treatments. For total species, ST and WT together enhanced similarity, which improved by about 2% with a 10 unit increase in each (Fig. 5a). The similarity of shrub species had a positive linear relationship with ST (Fig. 5c). The similarity of tree species had positive linear relation with ST and WT, with an interaction effect between ST and WT (Fig. 5d). The same was true for liana species, except there was no interaction effect (Fig. 5e).

4. Discussion

4.1. Effects of shading and watering on richness of germinated seedlings

The soil seed bank represents the pooled progeny of the current plant community as well as the potential species pool available for future communities to develop at a given place, and time (Fisher et al., 2009). Seed germination is the most vulnerable stage in the natural regeneration process and is sensitive to environmental conditions (Kyereh et al., 1999; Du et al., 2007), and seedling emergence is key to the successful restoration of terrestrial ecosystems (Liu et al., 2009). The feasibility of vegetation restoration using a soil seed bank is largely dependent on its species richness (Duncan et al., 2009). In our study, soil translocation with ST and WT effectively improved species richness, particularly herb and woody species, which was in accord with the study water is one of the most necessary conditions for seed germination in semi-arid and semi-humid areas (Ortiz et al., 2019; Muller et al., 2019) and shading improved environmental condition for seed germination (Nijjer et al., 2002). Our data indicate that the richness of total, herb, shrub, and tree species can reach 42.8, 20.1, 9.5 and 6.7 species, respectively, even without ST and WT (Fig. 3), suggesting that many species have adapted to the open environment and do not need shading and watering during the normal germination season. This result is in

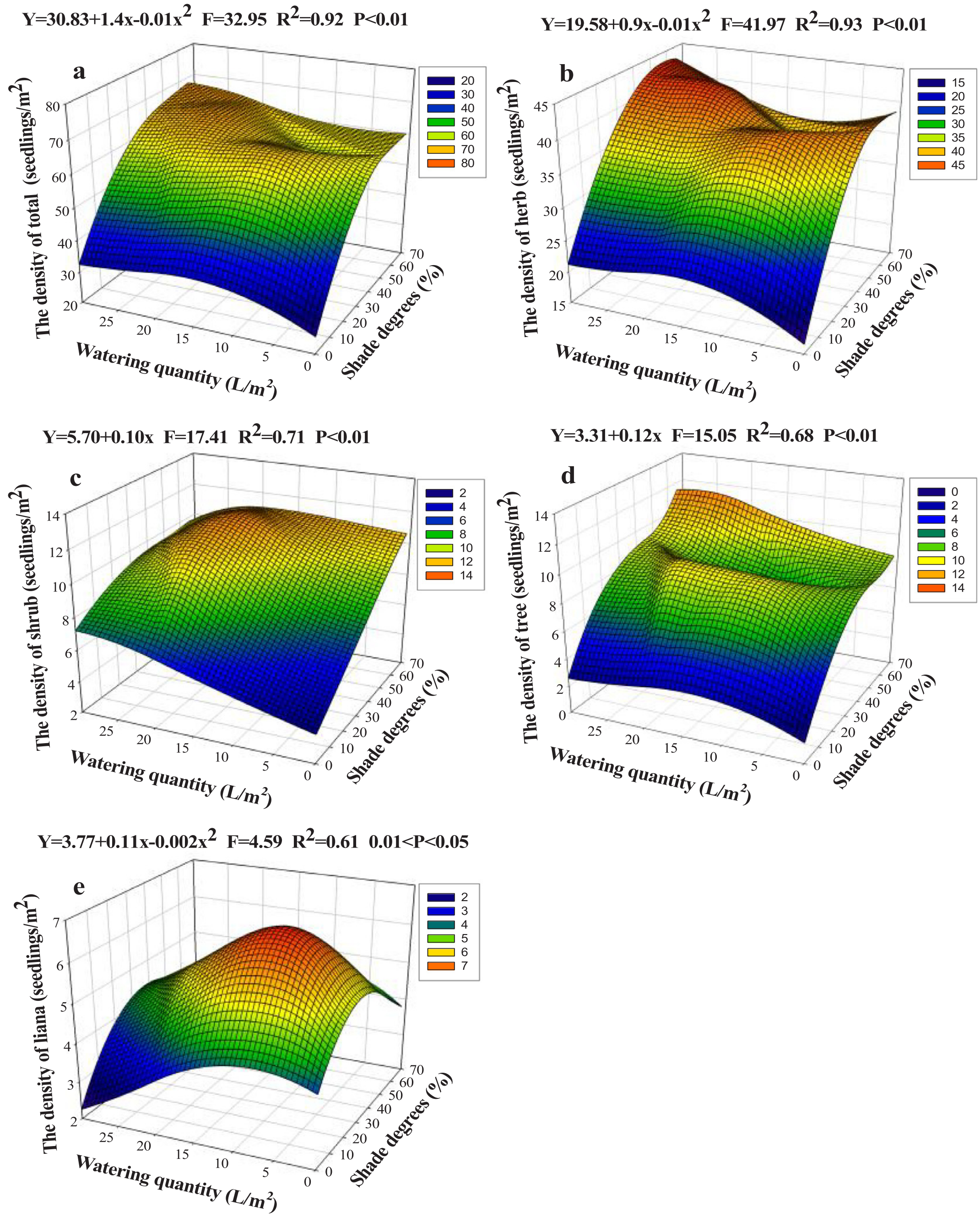

Fig. 4. Effects of shading and watering on total density and the density of different life forms germinated after forest topsoil translocation. Note: In the fitting equation, x is degree of shade, and Y is species density.

line with Vécrin and Muller (2003), who studied top-soil translocation as a technique in the re-creation of species-rich meadows in France but inconsistent with studies on European forest communities (Bossuyt and Honnay, 2008; Honnay et al., 2002). Moreover, we found that the effect of WT on richness was in the order total > herb > shrub species, while that of ST was total > herb > tree species, consistent with previous reports that herb species dominate the soil seed bank of forests (Bossuyt and Honnay, 2008; Sanou et al., 2019) and watering and shading further provided the favorable environment for seed germination (Metcalfe and Grubb, 1995; Zhang et al., 2012; Nijjer et al., 2002; Su et al., 2010; Sugahara and Takaki, 2004).

Although higher species richness and density were recorded among different treatments than donor forest, herb species accounted for about half of all species in both richness and density for each treatment in our results, which corresponded with the study that herb species dominated the seedlings during soil translocation (Metcalfe and Grubb 1995; Pywell et al., 2002; Warr et al., 1993). Moreover, most species were not from existing donor forest vegetation but rather from other seeds that had persisted in the soil seed bank and that broke dormancy upon receiving more light and water than was available in the donor forest (Cameron et al., 2000; Taab and Andersson, 2009; Takos and Efthimiou, 2003; Pywell et al., 2002; Warr et al., 1993), then ST and WT contributed significantly to their germination (Milberg et al., 1996; Hu et al., 2019). Additionally, the species composition ratio without ST and WT was herb > liana > shrub > tree species, but it transmuted into herb > shrub > tree > liana species or herb > tree > shrub > liana species for other treatments with WT and ST, similar to species composition of donor forest in our study. This shift suggests that

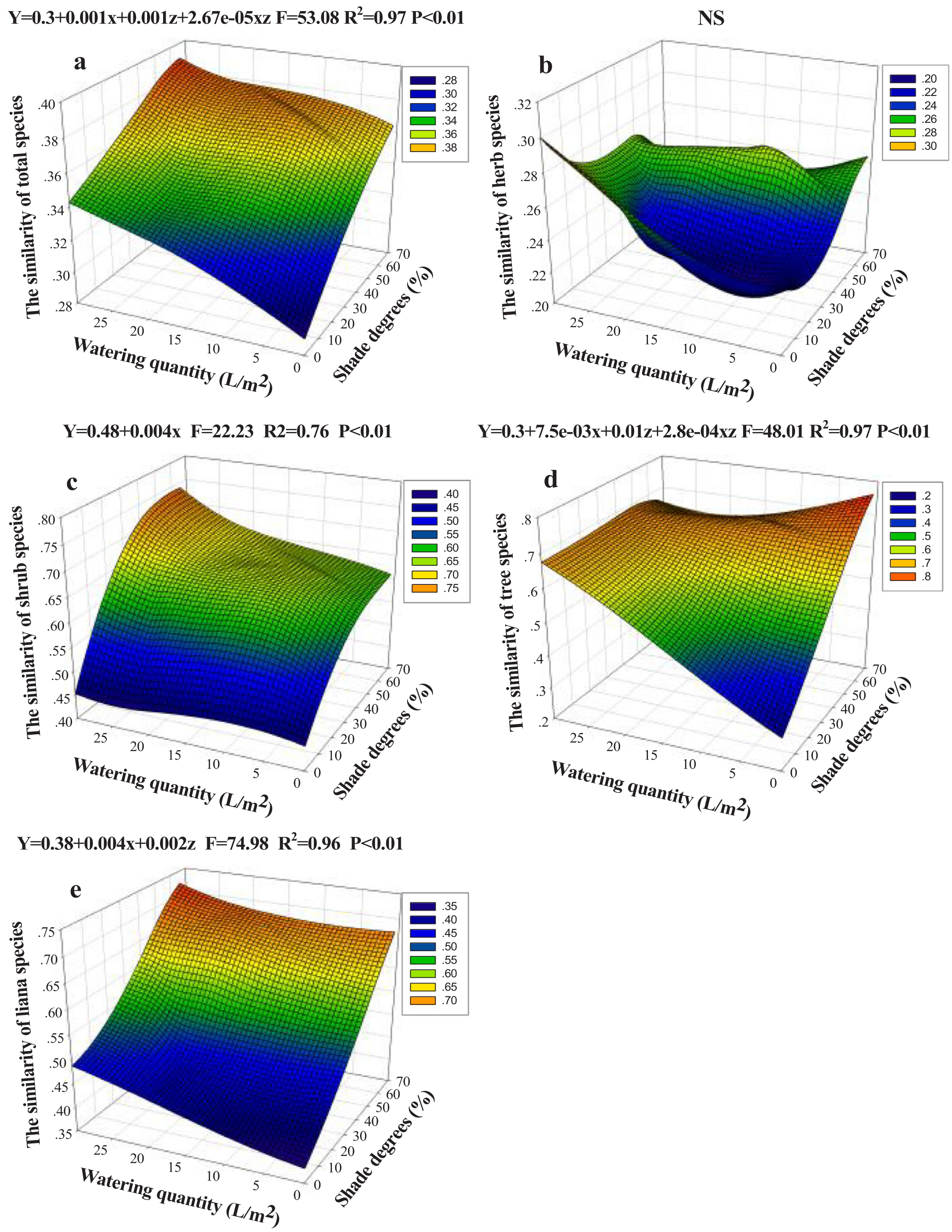

Fig. 5. Effects of shading and watering on similarity between germinated seedlings and donor forest vegetation. Note: In the fitting equation, x is degree of shade, z is water quantity, and Y is species richness; NS: not significant.

many tree and shrub species performed well at the receiving site when shading and watering was provided. Another study also showed that field natural conditions did not satisfy the germination requirements of woody species but contributed disproportionately to the germination of herb and liana species (Li et al., 2017).

4.2. Effects of shading and watering on density of germinated seedlings

The feasibility of vegetation restoration using a soil seed bank depends not only on species richness but also species density (Duncan et al., 2009) because the latter helps to determine seedling survival, future population growth and competition, and forest composition (Comita et al., 2014; Inman-Narahari et al., 2016). In our study, species density was only significantly affected by ST, in line with results that suggest that light plays a more critical role than water during seed germination (Ruano et al., 2009). In our study, the densities of total, herb, shrub, tree, and liana species only reached 30.8, 19.6, 5.7, 3.3, and 3.8 seedlings m^{-2}, respectively, without any treatment (Fig. 3), significantly lower than in other studies (Vecrin and Muller, 2003; Cristina et al., 2018) probably because the field conditions were different from the greenhouse conditions used in those previous studies, but our result was line with European forest community that had lower seed density (Bossuyt and Honnay, 2008; Bossuyt and Hermy, 2001). However, ST promoted the density of total, herb, and liana species at shade degrees of less than 70%, 45%, and 27.5%, respectively. On the contrary, shading restrained the densities of total species, herb, and liana species at shade degrees of more than 70%, 45%, and 27.5%. These results are in line with a previous study that found that light and moderate shading facilitated seed germination and severe shading deterred it (Orman et al., 2018; Zhang, et al., 2012).

4.3. Optimum strategies for effectively duplicating the diversity and similarity of a seedling community from a donor forest to a receiving site

The effects of ST and WT on richness and density were ultimately reflected by the similarity between germinated seedlings and donor forest vegetation. Similarities were low without any treatment, in line with previous works (Bossuyt and Honnay, 2008; Cristina et al., 2018; Hopfensperger, 2007). But the similarities of total species and woody species had a positive linear relationship with ST and WT in our result, which provide some references for the replication of similar forests. Additionally, soil translocation with ST and WT not only improved the germination of woody vegetation but increased the density of woody species. Therefore, in subtropical karst of China, soil translocation with ST and WT seems like a feasible method to effectively duplicate a diverse and similar forest to donor forest if soil translocation coincides with the rainy season.

5. Conclusion

Shading and watering treatments had strong effect on the richness, densities and similarity of woody species of translocated forest soil. The richness and densities of trees and shrub had positive linear relationship with ST or WT. The densities of total species, herbs and liana species presented a parabolic relation with ST. When shade degree exceeded 70%, 45% and 27.5%, the density of total species, herbs and liana species decreased respectively. In practice, putting soil under moderate or heavy shade (shade degrees range from 45% to 70%) is a promising method to duplicate a diverse and similar forest to donor forest if translocation process coincides with the rainy season. This finding can be incorporated into the practice and management of natural forest restoration and shorten the early stage of forest restoration and succession in subtropical karst of China and other similar regions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2019.117811.

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