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Fertile Island Soils Promote the Restoration of Shrub Patches in Burned Areas in Arid Saline Land

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Abstract: Shrub encroachment and expansion have been widely reported globally and are particularly severe in arid saline land. Shrubs in harsh habitats have fertile island effects, but the promoting effect of fertile island soil on shrub patch restoration remains unclear. To clarify the role of fertile island soils in shrub patch recovery, we took single *Tamarix ramosissima* shrubs with different volume sizes (3.62–80.21 m^3) as experimental subjects. The fertile island effect was quantified, and the 5-year natural recovery of shrub patches in the burned area was measured. The results strongly support that shrubs formed a fertile island soil in unburned areas; soil nutrient content beneath the canopy was 1.34–3.09 times higher than those outside the shrubs, while the soil salinity was 0.03–0.48 times lower than that of intercanopy spaces. The diversity of herbaceous plants beneath shrubs was significantly lower than that of outside shrubs, while the herbage biomass first increased and then decreased with the increase in the volume of shrubs. The maximum biomass of herbage was found when the shrub volume was 30.22 m^3, but oversized shrubs could inhibit the growth of herbage. In terms of burned area, the recovery of burned area mainly depends on resprouts and seedlings. The mean values of seedling density, height, coverage, and biomass beneath the canopies were 0.47, 2.53, 2.11, and 5.74 times higher, respectively, than those of the intercanopy spaces. The results of the structural equation models showed the weight coefficient of the fertile island soils for the vegetation recovery in burned shrubland was 0.45; low salinity contributed more to vegetation recovery than high nutrient and moisture contents. Thus, compared with intercanopy spaces, shrub patches reinforce fertile island effects through direct and indirect effects and enhance the recovery of shrubland vegetation in the burned area. Our results demonstrate the positive implications of shrub expansion in the context of global climate change and also deepen the understanding of the sustainable development of burned shrubland.

Keywords: fertile island; shrub expansion; vegetation recovery; burned area; *Tamarix ramosissima*

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1. Introduction

Shrub coverage and density increases have frequently been reported worldwide in tundra [1], wetlands [2], grasslands [3], meadows [4], and deserts [5]. Many studies have suggested that the shrub proportion increase is negative for ecosystem services in terms of loss of species and biomass [6], accelerated soil erosion [7], increased fuel loading, and advised control and removal of shrubs by cutting or fire [8,9]. While the expansion of woody plants may be negative for pastoral production and economic benefits, the ecological impact is not necessarily negative. In saline and arid spreading areas, the control of soil desertification and salinization by establishing vegetation and shrub expansion has occurred in arid salinized land, which provides new ideas for land management. Soil salinization is a global problem, and China is one of the countries with serious soil salinization [10,11]. The area of salinized land is 3.6×10^7 ha, accounting for 4.9% of available land, and the proportion of inland arid salinized soil has reached 60%, mainly distributed in northwest China [12,13]. In this context, it is necessary to consider the positive significance of shrub expansion and provide new ideas for soil salinization control.

Some previous reports have explained the positive role of shrubs in harsh habitats. In semi-arid Mediterranean grasslands, Maestre found that shrub encroachment enhanced vascular plant richness and predicted shrub expansion can reverse desertification [14]. Studies have reported positive effects on niche differentiation, as well as increased herbage biomass and topsoil organic carbon content [15–17]. In the Himalayas, facilitation by berberis shrubs promoted plant community diversity irrespective of season and elevation and showed the importance of facilitation by nurse shrubs in structuring plant communities and protecting important species, thereby enriching ecosystem services [18]. Shrub expansion increases soil spatial heterogeneity. Many reports have stated that soil available nutrients and total nutrients were higher beneath shrubs compared to surrounding areas [19,20], and soil organic matter was distributed similarly [21]. This phenomenon is known as the fertile island effect, which is a typical case of spatial heterogeneity linking canopy effects with plant interactions [22]. The term fertile island was coined to describe nutrient accumulation in deserts in Utah, meaning that soil beneath the canopies of some woody plants was significantly more fertile than that in intercanopy spaces [23]. The influence of shrubs on rainfall and soil moisture evaporation results in soil salinity heterogeneity [24,25], and it is believed that fertile islands are the basis for the stability of desert vegetation in a habitat with limited soil nutrients and water [15,17].

Shrubs can use water at a deeper level compared to herbs, making it possible for them to survive and expand in arid areas. Additionally, enhanced taproot elongation of shrubs could give nascent seedling growth and expansion advantages, helping reduce competition with herbage [26]. Conversely, herbaceous plants that grow in the shrublands of arid regions are mostly ephemeral, putting more energy into seed production in arid regions [27]. While shrubs and herbs differ in their ability to rehydrate, this can shift as disturbance changes. A continual increase in disturbance would further decrease the rehydration capability of grasses, leading to an increase in shrub coverage, which would be irreversible [28]. Fire is the most common disturbance in shrubland [29], but the clear effect of fire treatment on shrub patches often has limited efficacy because many shrubs resprout and rapidly reestablish abundance in burned areas [8].

Many studies have focused on the ecological processes and consequences of shrub expansion. Shrubs provide a refuge for grass [30], increase soil moisture [31], buffer soil temperature, enhance soil fertility [32], adjust soil pH [33], influence soil salinity distribution [24,25], and provide resistance to fire disturbances [8]. Therefore, we believe that the strong recovery capacity of shrub patches compared to desert grasslands (shrub interspaces) is an important factor promoting shrub expansion. This is attributed to the interaction of shrubs and herbage, as well as to the fertile island soils. Here, we chose *Tamarix ramosissima* shrubs of different sizes as research objects. *T. ramosissima* is a typical shrub with special salt glands and is well adapted to dry and salt soil, so it can tolerate an extreme range of environmental conditions [20]. We hypothesize the following: (1) Shrubs can shelter herbage and herbaceous diversity, and biomass beneath shrubs is higher than that outside the shrubs. (2) The soil nutrient content beneath the shrub is higher than that outside the shrub, while the salinity is lower than that outside the shrub, which is more favorable for plant growth. (3) In burned shrublands, the number and height of shrub resprouts and the height, density, coverage, and biomass of herbage seedlings are higher in shrub patches than in intercanopy spaces. The above predictions are controlled by the size of the shrub. To test the above hypotheses, we designed experiments consisting of two parts: (I) Herbaceous communities and soil properties beneath different sizes of shrubs without fire disturbance were investigated to quantify fertile island soils. (II) The vegetation was surveyed from resprouts and seedlings in the shrubland, which was naturally restored 5 years after a fire.

2. Materials and Methods

2.1. Site Description

The study area is located in Jiuquan City, Gansu Province (39°40′03.23″ N, 98°49′17.80″ E, 1385.7 m above sea level), with a temperate continental arid climate. The experimental site is located in a transitional zone of desert and oasis, which is a key area of desertification and salinization prevention and control. The mean annual precipitation of the area is 87.7 mm, mostly concentrated from June to October. The average annual evaporation is 2140 mm, which is 24.4 times higher than the average annual precipitation [34]. The mean value of salinity in the 0–10 cm soil layer was 5.0 g/kg, and the pH value was 8.1. The average wind speed is 2.3 m/s–26.0 m/s, the average temperature is 7.3 °C (−9.9 °C in January and 22.2 °C in July), and the annual frost-free period is 132 days [35].

We found that coverage of *T. ramosissima* has expanded by 19.7% over the past 30 years at the experimental site, with areas of 129.6 ha in 1989 and 155.1 ha in 2019, of which 29.3 ha were severely burned in 2004. Burned and unburned areas provide a natural experimental site for evaluating the recovery of dry shrublands after a fire. It is characterized by limited water availability and hot spots of soil salinity, with a plant community structure dominated by shrubs and xerophytic and salt-resistant perennial herbage belonging to *T. ramosissima*, *Kalidium foliatum*, *Nitraria sibirica*, *Achnatherum splendens*, and *Lycium ruthenicum* and annual and perennial herbaceous plants, such as *Aeluropus sinensis*, *Leymus secalinus*, *Cirsium setosum*, *Suaeda glauca*, *Alhagi sparsifolia*, *Phragmites australis*, and *Chenopodium album* as accompanying species.

2.2. Vegetation Survey and Soil Sampling of Shrub Patches

A total of 75 individual *T. ramosissima* shrubs of different sizes were randomly selected, and their height and canopy diameter were measured with a tape measure in August 2019. Plant and soil samples were taken at the experimental site. An herbage survey was conducted in four different directions beneath and outside the canopy using quadrats (0.5 m × 0.5 m). We measured and recorded species number, height, coverage, and density of herbage and then cut all the herbage above the ground in the quadrats (Figure 1a,b). All plant samples were placed in envelopes. Our previous experimental results showed that differences in soil properties around *T. ramosissima* occurred mainly in the 0–40 cm soil layer [34]. Therefore, 0–40 cm soil samples were obtained from four directions beneath and outside the canopies of shrubs with different sizes by using soil drills with a diameter of 3.5 cm, and the soil samples in four directions were mixed into one sample (Figure 1b). The soil samples were evenly mixed, and plant roots and stones were removed. Soil (0.5 kg) was placed in a self-sealing bag and transported to the laboratory. The soil moisture content was measured immediately, and the soil nutrients and salinity were measured using the remaining soil samples after natural air drying. The same method was used to obtain vegetation and soil samples in the intercanopy spaces, repeated eight times.

2.3. Restoration of Shrub Patches in Burned Areas

In March 2014, a fire occurred at the experiment site, and no above-ground live plants were found in burned area. The obliterated vegetation facilitates the assessment of vegetation restoration (Figure 1c). In August 2019, we surveyed the naturally restored vegetation from resprouts and seedlings in the burned area by measuring the height and canopy size of 60 individual, intact, dead, and standing *T. ramosissima* and by counting and measuring the height of the resprouts and the density, height, coverage, and biomass of seedlings beneath and outside the canopies (Figure 1d). Resprouts are new buds or branches that grow from the plant residue in the burned area, and seedlings are new individuals that germinate from soil seeds. Herbaceous plants are categorized as resprouts if there is plant residue at each base or as seedlings if there is none. The herbage measurement and soil sampling methods were the same as those described in Section 2.2 (Figure 1b).

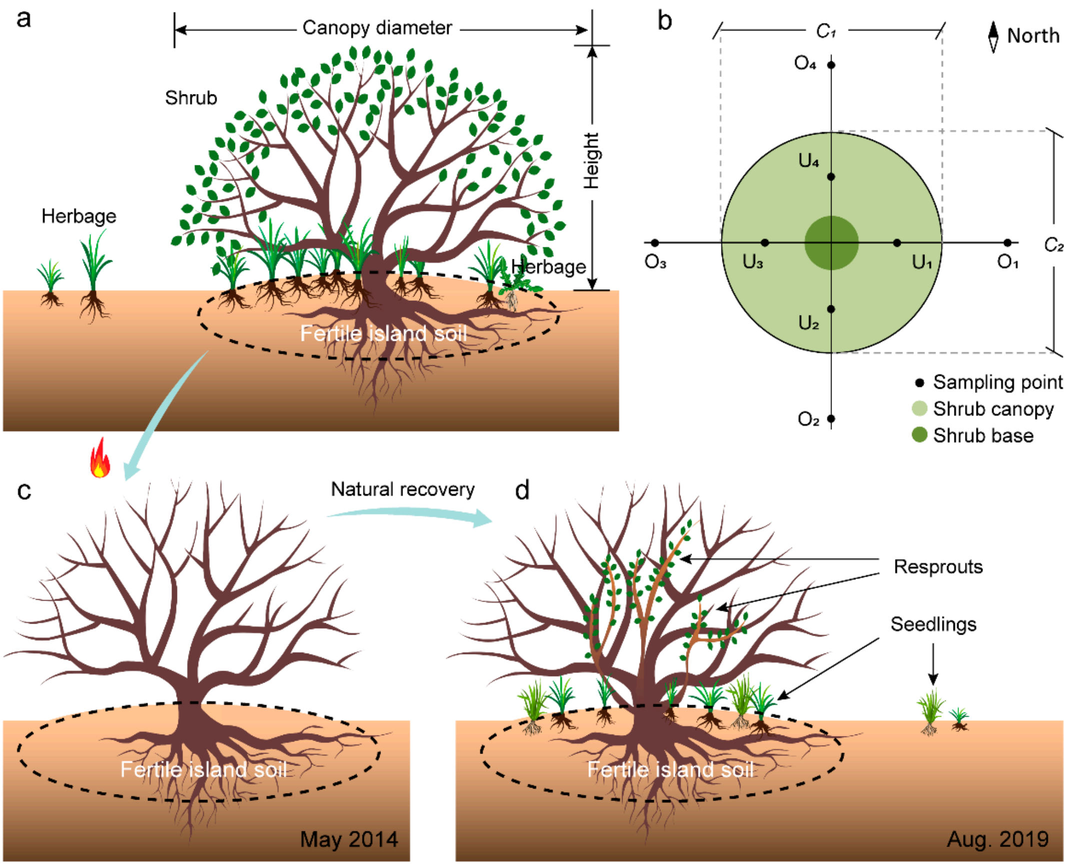

Figure 1. Experimental design and sampling. The experiment consisted of two parts: (1) a survey of different sizes of single shrubs and their surrounding herbage, and determination of fertile island soil properties (**a**). (**b**) shows the herbage survey and soil (0–40 cm) sampling method (vertical view). Dark atrovirens represent the shrub base, and light atrovirens indicate the canopy; the unfilled zone represents intercanopy spaces. U_1–U_4 and O_1–O_4 were sampling points, with U points beneath the canopy and O points outside the canopy; 1–4 soil samples were mixed to form one sample. (2) A natural recovery assessment of burned areas (**c**,**d**). The sampling method around a single dead standing shrub was the same as in (**b**). More details are provided in the main text.

2.4. Laboratory Analysis

All plant samples were immediately oven-dried at 105 °C for 30 min, at 80 °C for 48 h, and weighed as plant above-ground biomass. Soil samples were air-dried and sieved through 1.0 mm and 0.25 mm mesh sieves to analyze the main properties. Soil moisture (SM) content was calculated after drying samples at 105 °C for 48 h, and soluble concentrations of primary nutrients such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, and SO_4^{2-} were analyzed using soil–water suspension (1:5 *w*/*v*), and soil soluble salt (SS) was measured by weighing the residue [36]. Soil organic carbon content was determined using the Walkley and Black method through wet oxidation of organic carbon with $K_2Cr_2O_7$-H_2SO_4 [37]. To eliminate the effect of Cl^{-} in the soil, Ag_2SO_4 (0.1 g) was added for conversion of Cl^{-} to AgCl. The percentage of soil organic matter (SOM) content was obtained by multiplying the percentage of soil organic carbon by a factor of 1.724 [38], which is based on the theory that organic carbon constitutes 58% of the SOM. Soil total nitrogen (TN) content was analyzed using the Kjeldahl digestion method [39], with mixed catalysts (K_2SO_4:$CuSO_4$:Se = 100:10:1). Soil available nitrogen (AN) was measured according to the alkaline hydrolysis diffusion method. Soil total phosphorus (TP) was initially measured using a mixed solution (concentrated H_2SO_4 and $HClO_4$), and then phosphorus concentrations in the digested and extracted supernatant liquor were analyzed spectrophotometrically (Spectrophotometer UV-1800, Shimadzu, Kyoto, Japan). Soil available phosphorus (AP) was quantified using the molybdenum antimony colorimetric method (Spectrophotometer UV-1800, Shimadzu, Japan). Soil total potassium (TK) content was assessed using the sodium hydroxide fusion–flame spectrophotometer method (Flame photometer PFP7, Stone, Chelmsford, UK), and soil available potassium (AK) content was analyzed on a flame photometer (Flame photometer PFP7, Stone, UK) by NH_4OAc extraction. For the detailed operation steps of AN, TP, TK, and AK, refer to the study of Bao et al. [36].

2.5. Quantification of Shrub Volume and Plant Diversity

The shrub volume size (SVS) and diversity of the herbage plants were calculated; the formulas are as follows [40]:

$$\text{SVS} = \pi C_1 C_2 H/4 \tag{1}$$

$$\text{Relative important value } (P) = \left(\overline{X}_{density} + \overline{X}_{height} + \overline{X}_{coverage} + \overline{X}_{biomass}\right)/4 \tag{2}$$

$$\text{Margalef index} = (S-1)/\ln N \tag{3}$$

$$\text{Simpson index} = 1 - \sum_{i=1}^{s} {P_i}^2 \tag{4}$$

$$\text{Shannon} - \text{Wiener index} = -\sum_{i=1}^{s} (P_i \ln P_i) \tag{5}$$

$$\text{Pielou index} = -\sum_{i=1}^{s} (P_i \ln P_i)/\ln S \tag{6}$$

where C_1 and C_2 are shrub canopy diameters (C_1 and C_2 are perpendicular to each other; Figure 1b), and H indicates shrub height. X_{index} is a relative value of an index, P_i represents relative important values of i, N represents the number of individuals, and S indicates the number of species in a quadrat.

2.6. Statistical Analysis

The structural equation models (SEMs) were constructed by Amos software version 22.0 (IBM Corporation, Armonk, NY, USA). Height, canopy diameter, and SVS were observed variables for shrubs. Species number, density, above-ground biomass, and diversity indices (Margalef, Simpson, Shannon–Wiener, and Pielou indices) were observed variables for herbage. The soil was characterized by moisture, salinity, and fertility, and vegetation recovery was measured by resprouts and seedlings. The soil salt content was treated by reciprocal treatment. We used factor analysis (SPSS software version 22.0) to decrease the dimensionality of the above potential variables to quantify soil salinity and fertility and then fit the SEMs. Other statistical analyses and plotting were performed by ORIGIN software version 8.5 (Origin Lab Corporation, Northampton, MA, USA) and R software version 4.1.1.

3. Results

3.1. Features of Herbage Beneath Shrubs in Unburned Area

The number of grass species was lower than that of intercanopy spaces. The number of species in each quadrat outside the canopy was 4–6, but 0–5 species of herbage were found beneath the canopy (Figure 2a). The larger the shrub, the lower the species number beneath the canopy, or even no species were observed. The variation trends of the Simpson index, Shannon–Wiener index, Margalef index, and Pielou index were similar to those of the grass species, which gradually decreased with the increase in SVS, with values of 0.54, 0.48, 0.64, and 0.82. The results showed that the community structure was simple, and the species diversity was low (Figure 2). However, the above-ground biomass of herbage first increased and then decreased with the increase in shrub size. The maximum value of above-ground biomass was found when SVS was 30.22 (Figure 2b). Compared with beneath the canopies, the grass diversity outside the shrub area was rich, but the biomass was low.

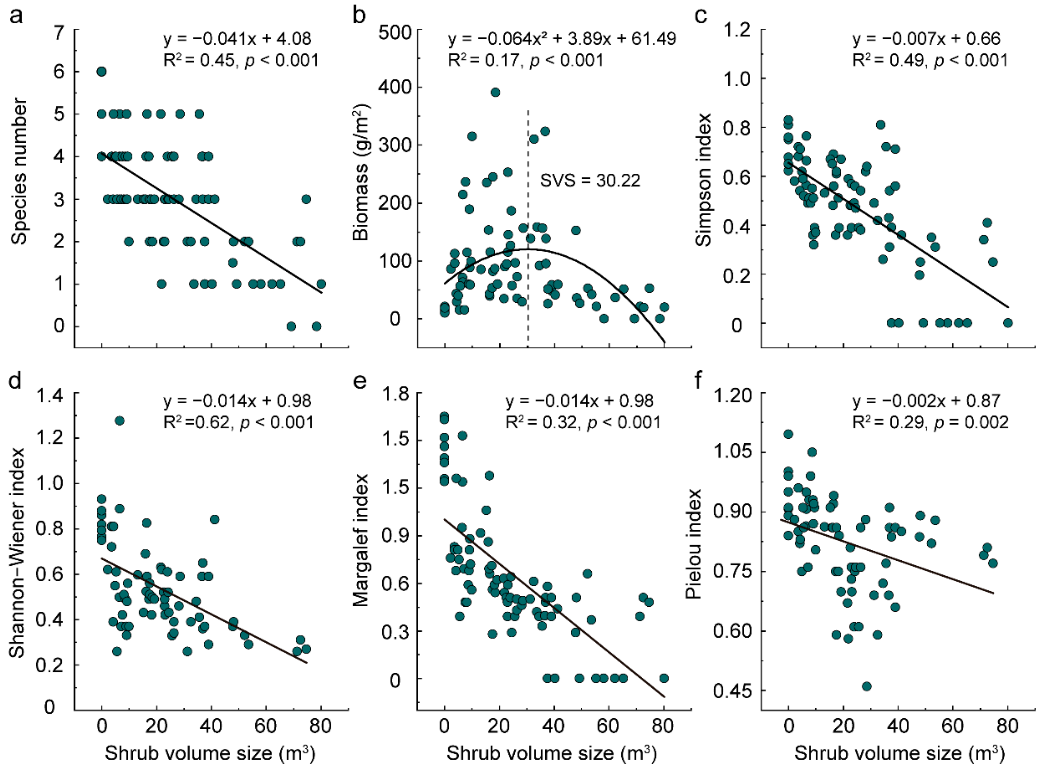

Figure 2. Characteristics and diversity of herbage plants beneath shrubs with different volumes, showing species number (**a**), above-ground biomass (**b**), Simpson index (**c**), Shannon–Wiener index (**d**), Margalef index (**e**), and Pielou index (**f**). The dotted line indicates the shrub volume at the maximum herbage biomass in (**b**), and dots represent single observations in (**a**–**f**).

3.2. Soil Properties Beneath the Shrub Canopy in Unburned Area

Shrub existence intensified the soil spatial heterogeneity. Soil moisture and nutrients beneath the canopy were higher than those in the intercanopy spaces, while the soluble salinity was lower than that outside the shrub canopy. Shrub size was also a major factor that affected the soil properties; the soil moisture beneath the canopy increased gradually, but the extent of the increase decreased gradually with the increase in SVS. Soil nutrient content showed a single peak change, while soil soluble salt showed a "V" change trend (Figure 3). CO_3^{2-}, which is most harmful to plants, was not detected at the experimental site.

The extreme values of the soil indices were analyzed (Table 1). Concerning indexes of soil nutrient content, the soil beneath the canopy was 1.33–3.08 times higher than outside the canopy. However, the soluble salt in the soil beneath the canopy was 43% of that in the soil outside the canopy. The content of soil ions beneath the shrubs was 3–48% of that outside the canopy, and the difference in Na^+ was the largest. When SVS was 80.21, the maximum soil moisture beneath the canopy was 10.66%, and that outside the canopy was 6.42%. When SVS was 23.96, 23.96, 23.90, 23.04, 19.25, 21.56, and 25.63 m^3, maximum values of SOM, AN, AP, AK, TN, TP, and TK, respectively, were found. Soil soluble salt was 3.22 g/kg beneath the shrubs and 7.56 g/kg outside the shrubs, with an SVS of 23.96. Ca^{2+} was the dominant cation, and SO_4^{2-} was the dominant anion in the soil beneath the canopies, with values of 0.41 and 0.13 g/kg, respectively. The maximum value of soil nutrients and the minimum value of soil salinity occurred beneath the shrubs when SVS was about 26.50, which is similar to the variation pattern of the herbage biomass.

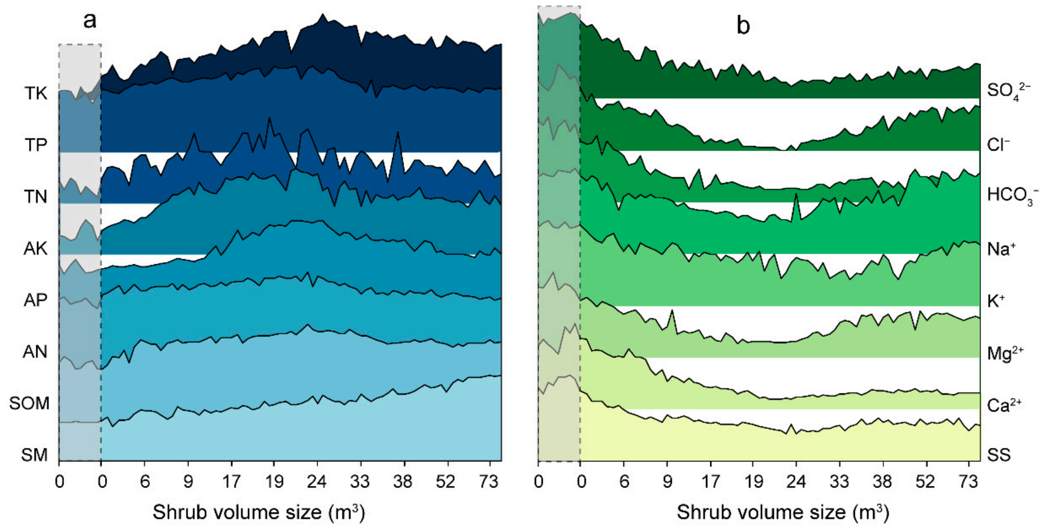

Figure 3. The variations of moisture, fertility (**a**), and salinity (**b**) in fertile island soils with increasing shrub volume. CO_3^{2-} was not detected. Light gray (shrub volume values were zero) represents the intercanopy spaces. SM, soil moisture; SOM, soil organic matter; and SS, soluble salt.

Table 1. The difference in soil properties beneath and outside the shrubs showing maximum values of soil properties beneath and outside the shrubs with corresponding shrub volume sizes (SVS; m^3).

Soil Properties	Outside	Beneath	Beneath/Outside	SVS (m^3)
Soil moisture (%)	6.42	10.66	1.66	80.21
SOM (g/kg)	1.11	1.68	1.52	23.96
AN (mg/kg)	21.21	28.42	1.34	23.96
AP (mg/kg)	12.55	21.03	1.68	23.90
AK (mg/kg)	229.29	504.16	2.20	23.04
TN (g/kg)	0.06	0.14	2.47	19.25
TP (g/kg)	0.44	0.58	1.33	21.56
TK (g/kg)	2.60	8.04	3.09	25.63
Soluble salt (g/kg)	7.56	3.22	0.43	23.96
Ca^{2+} (g/kg)	1.52	0.41	0.27	23.90
Mg^{2+} (g/kg)	0.44	0.13	0.30	18.56
K^+ (g/kg)	0.05	0.02	0.41	22.59
Na^+ (g/kg)	0.25	0.12	0.48	22.59
HCO_3^- (g/kg)	0.18	0.05	0.27	24.18
Cl^- (g/kg)	0.22	0.03	0.14	23.96
SO_4^{2-} (g/kg)	4.68	0.13	0.03	24.26

Abbreviations: SOM, soil organic matter; AN, available nitrogen; AP, available phosphorus; AK, available potassium; TN, total nitrogen; TP, total phosphorus; and TK, total potassium.

3.3. Vegetation Recovery of Shrubland in Burnrd Area

Recovery of shrub resprouts and herbaceous seedlings on fertile islands was better than outside fertile islands in burned areas (Figure 4). In the intercanopy spaces in the grassland, resprouts were not found, and seedling growth was the main recovery pathway. Thirteen herbaceous species were found in burned shrublands, and they belonged to Poaceae, Asteraceae, and Amaranthaceae. The dominant species of seedlings were *Agropyron desertorum*, *L. secalinus*, *N. splendens*, *Calamagrostis epigeios*, and *Cirsium arvense* (Table S1). The mean values of the seedling density, height, coverage, and biomass were 314.02 ind./m^2, 0.68 m, 65.51%, and 83.75 g/m^2, respectively. Sprouts (number and height) and seedlings (height and biomass) increased with shrub volume size ($p < 0.05$). There was no strong linear relationship between the effect of shrub volume size on the density ($p = 0.06$) and coverage ($p = 0.47$) of seedlings under the canopy (Figure 4c,e). Many dead *T. ramosissima* were preserved intact because of the dry climate and grazing exclusion. Vegetation restoration depended on the growth of resprouts and seedlings beneath the canopy. The number of resprouts increased with the increase in SVS, with a maximum value of 91 individuals for a single shrub. The resprout height reached 1.94 m, which was significantly higher than that of seedlings, providing a shaded environment for other plants and animals. The mean values of the seedling density, height, coverage, and biomass beneath the canopies were 1.49, 3.57, 3.02, and 6.84 times higher than those in the intercanopy area.

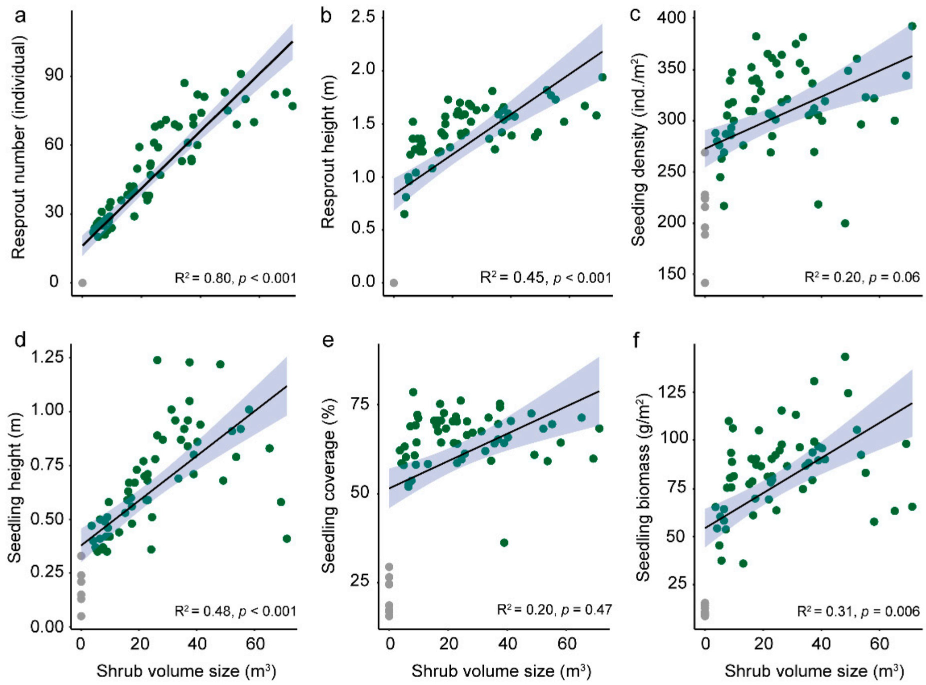

Figure 4. The vegetation restoration beneath shrubs with different volumes in the burned area, including resprouts and seedlings. The number (**a**) and height (**b**) of resprouts and the density (**c**), height (**d**), coverage (**e**), and biomass (**f**) of seedlings were measured. The gray point indicates the recovery effect in intercanopy spaces (the shrub volume size was 0).

3.4. SEMs of Shrub Patch Restoration

The existence of shrubs in arid saline–alkali areas improved the restoration effect of vegetation, with a direct correlation coefficient of 0.76, shown in Figure 5a. In the burned area, shrubs also influenced the soil's physical and chemical properties by sheltering herbaceous plants, with a correlation coefficient of 0.16. Fertile island soil can promote vegetation restoration in the burned area, and the correlation coefficient was 0.45. The direct influence of shrubs on the fertile island soil was weighted at 0.1, while the influence of herbage on fertile island soil was weighted at 0.21, suggesting that herbage plays an important role in the formation of fertile island soil. Further, the effects of fertile islands on the formation and vegetation restoration were analyzed based on soil moisture, salinity, and fertility in Figure 5b. Shrubs and herbage increased the soil water and nutrients to different degrees and decreased the soluble salt in the soil beneath the canopy. It is worth noting that herbage had a greater inhibitory effect on soil salinity compared to shrubs, with a coefficient of 0.49. For the recovery of shrubland after a fire, the 5-year recovery results showed that shrub resprouts were affected by soil moisture and salt, and the effect of salt accounted for 51.1%, while the effect of soil nutrient content was not significant. Herbage seedlings were affected by soil moisture, salt, and nutrients, and the influence weights were 8.9%, 51.1%, and 40.0%, respectively. Therefore, the recovery of resprouts was mainly driven by soil moisture and salinity (Figure 5c), while the seedling restoration was driven by the joint action of soil moisture content, salinity, and nutrients. Compared with soil moisture and nutrients, soil salinity has a greater impact on seedlings, with an impact coefficient of −0.69 (Figure 5d).

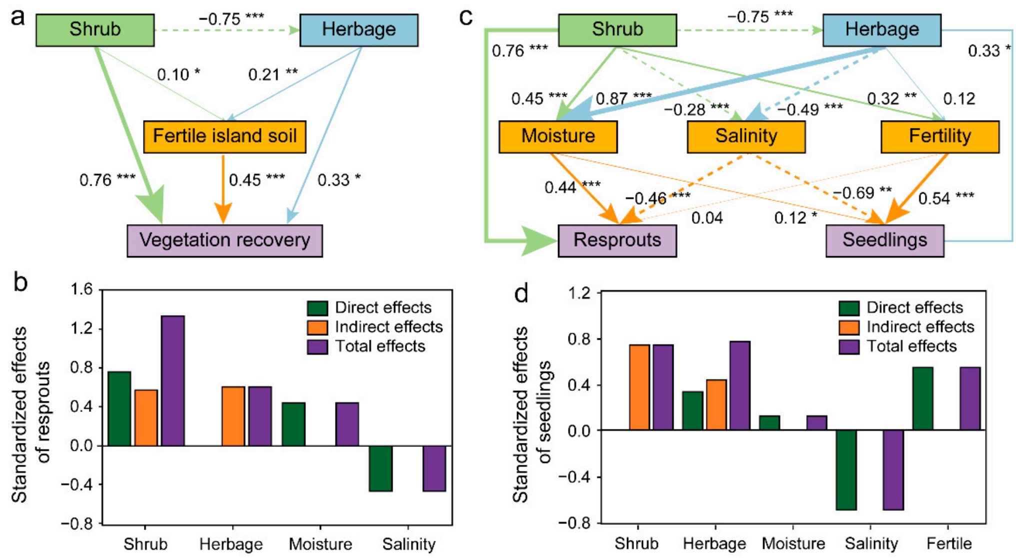

Figure 5. SEM between shrubs, herbage, soil, and vegetation recovery in (**a**), and more detailed effects in (**b**). For each standardized coefficient, *p* values are given alongside lines and indicated by asterisks (* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$), and the line weights are proportional to the standardized coefficients. The solid line indicates a significant correlation ($p < 0.05$), and the dashed line indicates an insignificant correlation ($p > 0.05$). (**c**,**d**) show the standardized effects of resprouts and seedlings, respectively. Models fit the data well; CMIN/DF = 2.75, AGFI = 0.88, and CFI = 0.98 in (**a**), and CMIN/DF = 3.87, AGFI = 0.94, and CFI = 0.92 in (**b**).

4. Discussion

Shrubs are regarded as nurse plants because woody plants are usually taller than grass and provide a refuge for herbage in arid and semi-arid regions [23,41]. In this study, tamarisk was the absolute dominant shrub, although other shrub species were present with a small coverage, such as *K. foliatum*, *N. sibirica*, and *L. ruthenicum*. Numerous previous studies have shown that shrubs significantly increased the biomass of herbage beneath the shrubs [42,43]. Shrubs provide a warm microenvironment for herbaceous plants. The literature suggests that nighttime air temperature was higher in the shrubland than in the grassland (>2 °C) during calm winter nights in Sevilleta [44], and a similar phenomenon has been observed in the southwestern United States [45]. In addition, when shrub coverage was increased to 32.4%, shrubs showed earlier onsets and later ends of the plant growing season, and the growth time was increased by 15–22 days [46]. However, our results showed a negative correlation between shrubs and herbage. The results are not contradictory; shrub size is an important factor that affects herbaceous plants, especially in relative canopy diameter [47]. We found that with an increase in shrub size, herbage biomass first increased and then decreased, and the maximum value was found when SVS was 30.22 m^3. The total competitive effect of woody plants was significantly greater than that of grass [48]. When SVS was greater than 30.22 m^3, the nurse effect gradually decreased, and even the herbage could not survive. Moreover, shrub roots can reach a depth of 3 m and can absorb water from deep soil layers and release water to shallow soil at night, which is conducive to the development of plants with shallow roots [49,50]. In summary, the trade-offs between facilitation and competition for shrubs and herbs are complex and involve a variety of ecological processes, such as litter decomposition [51] and root renewal [52]. The soil water-holding capacity and attraction to herbivores also promote the growth of shrubs [17,31].

The fertile island effect is an ecological consequence of shrub expansion, which was quantified based on soil water, nutrients, and salts in this study. The canopy can effectively reduce the evaporation of soil water. Salt moves with water, and the soil salinity beneath the shrubs was significantly lower than that outside the canopy area in this study, and the value was the lowest when SVS was 23.96 m^3. The large canopy of shrubs and herbage reduced the evaporation of soil moisture. However, a study found that the soluble salt content in the stem runoff was significantly higher than that in rainfall [53], but soil evaporation is still the dominant factor in salinity distribution in arid areas. Shrubs can absorb soil nutrient content from outside the canopy area and deep soil and return nutrients to the topsoil through litter [51,54]. Shrubs provide a habitat for animals in arid areas, and animal waste is an important source of nutrients in the soil [15]. Shrubs and herbage can also further enhance soil nutrient content through root shedding and decomposition [52]. A study found that microbial biomass beneath the canopy was much higher than that outside the shrubs [24,55], which promotes the decomposition of litter, plant roots, and animal waste and remains. Thus, the fertile island soil region is the center of plant and environmental communication in arid saline zones. Material cycles and information exchange pathways are more complex beneath the canopies compared with intercanopy spaces. The heterogeneous environment is conducive to the survival and communication of plants, animals, and microorganisms in harsh habitats, which can stop and even reverse soil desertification and salinization.

Finally, the fertile island soil of the shrub patches is an important factor in promoting vegetation recovery. The emergence of shrubs provides a complex ecological memory for the burned area. Plant residues, bud banks for the resprouting species, and soil seed banks for the seedling species represent biological memory, and soil moisture, salt, and nutrients represent non-biological memory [56,57]. Resprouts and seedlings contributed to the recovery of shrubland, and the height of resprouts was significantly greater than that of seedlings. Resprouts mainly depend on the survival of remnant *T. ramosissima*. The roots of shrubs are deep and store high amounts of energy, and their recovery rate was significantly higher than that of seedlings. Shrubs are less likely to die by fire than herbs, and stumps provide a material base for vegetation restoration [58]. The height and biomass of seedlings beneath the canopy were much higher than that in the intercanopy spaces in the burned area. Shrubs can intercept seeds that depend on the wind for propagation by the canopy, and seeds are concentrated beneath the canopy to form a rich soil seed bank [59]. In general, light is an essential resource for promoting seed germination. However, strong light inhibits the germination of large seed masses, suitable amounts of light are beneficial for maintaining high species richness, and light availability controls community composition and structure [60]. The strong UV radiation in the experimental area and the attenuation of light intensity by the canopy favored seedling establishment. There were significantly higher soil nutrient content and water beneath the shrubs compared with the intercanopy spaces, and soil salinity was significantly lower than that outside the shrubs. Vegetation restoration is a specific manifestation of community stability, and the interaction between shrubs and herbage can enhance the stability of shrublands through fertile islands.

Thus, *T. ramosissima* can survive well and expand in arid and saline land, which benefits not only from its physiological structure of salt tolerance [61] but also from fertile island soils. The shrub has an inhibitory effect on desertification and salinization, which can provide ideas for the prevention and control of soil desertification and salinization. We believe that "fertile islands" should not only describe the spatial heterogeneity of soil nutrient content but also further expand the boundaries of fertile island theory with respect to nurse plants, animals, microorganisms, and the inorganic environment. It is the result of plant interactions in harsh habitats and is evidence of an ecological legacy with complex internal feedback and self-organization. This study measured the status of 5-year natural recovery of shrub patches after a fire and refers to the important role of fertile islands in this process. The structure, circulation, and feedback of fertile islands need further study.

5. Conclusions

Shrub expansion occurs globally, increasing the spatial heterogeneity of soil resources. In unburned areas, we found low salt content and high nutrient content in the fertile island soils compared to those in the intercanopy spaces. When SVS was 19.25–25.63 cm^3, the soil nutrient and salt contents showed maximum and minimum values, respectively. The moisture content of fertile island soils increased with increasing SVS, and the value was significantly higher than that of intercanopy spaces. The mutual feedback between shrubs and herbage is an important cause of the fertile island effect. Shrubs shelter herbage and increase herbage diversity and biomass, but a canopy that is too large is not beneficial for herbage growth. When SVS exceeded 30.22 m^3, the herbaceous biomass decreased gradually. In turn, the herb significantly increased the moisture and significantly reduced the soil salt content of fertile island soils. In burned areas, the larger the SVS of the shrub, the better the effect of patch recovery in 5 years. Shrub residue and fertile island soils serve as ecological legacies, enhancing the growth of shrub resprouts and seedlings in the patches. Our results show that the interactions of shrubs and herbs formed fertile island soils, which had a positive effect on the restoration of shrub patches in the burned area. This may be an important reason for the expansion of shrubs in arid and saline land. Therefore, *T. ramosissima* can be considered a plant species for soil improvement and vegetation recovery in arid saline soils.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/fire6090341/s1. Table S1: Features of plant species restoration in burned shrubland (*T. ramosissima*).

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