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DISTRIBUTION OF SOIL SEED RESERVE AND ITS ASSOCIATION WITH ABOVEGROUND VEGETATION IN SALINIZED SOILS OF ARID REGIONS IN NORTHWEST CHINA

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Abstract

The seed bank of salinized soil is a valuable germplasm resource for plant salt tolerance research. The study collected 468 soil samples from plant communities of 5 subtypes and 13 soil genera in saline-sodic badland of northwest China in spring, summer, and autumn, 2015, respectively. The seed from the soil samples was germinated in lab and species were identified. There were 34 species from 14 families and 31 genera that mainly belong to Chenopodiaceae, Gramineae, and Compositae. However, identification of the aboveground vegetations found that there were 21 species from 9 families and 19 genera that mainly belong to Chenopodiaceae and Poaceae. The difference in species between the aboveground vegetation and the soil seed bank was mainly in herbaceous plants, which had strong adaptability to salinity and alkalinity. The soil seed reserves were small and simple in species composition, with most species being indicator halophytes of desert. In spring, summer, and autumn, soil seed densities in the 5 subtypes of saline soil decreased in the order of meadow solonchaks > orthic solonchaks > dry solonchaks > bog solonchaks > alkalized solonchak. However, there was no significant difference in soil seed density between spring, summer and autumn. Soil seed bank showed a significant vertical hierarchy. The correlation between soil seed bank and aboveground vegetation is small in salinized and arid regions.

Key words: 5 Soil subtypes and 13 soil genera, Salinized soil, Soil seed banks, Species identification, In arid and salinized areas.

Introduction

Soil salinization is a type of land degradation that can lead to desertification. The detrimental effects of soil salinity on agricultural production is significant because it reduces the growth and productivity of plants (Mathur *et al*., 2007). The accumulation of soil salts also changes the environment of plant growth, results in shifts of plant types to that of salt and desert communities and finally leads to the deterioration of ecological environment. Gansu Province, China is located on the convergence zone of the Tibetan Plateau, the Loess Plateau, and the Mongolia Plateau. The zone is a mountainous plateau terrain with complex landforms including mountain, basin, plain, desert, and Gobi. The climate types from southeast to northwest in Gansu Province include the typical climate types of north subtropical humid areas, high-altitude and cold areas, and arid areas.

Saline soils (Salt content ≥1.0%) in Gansu Province can be classified into 5 subtypes: meadow solonchaks, orthic solonchaks, bog solonchaks, alkalinzed solonchak, and dry solonchaks. There are 13 soil genera that include sulphate-type meadow solonchaks, chloride-sulphate-type meadow solonchaks, sulphate-chloride-type meadow solonchaks, chloride-type meadow solonchaks, sulfate-type orthic solonchaks, chloride-sulfate-type orthic solonchaks, sulfate-chloride-type orthic solonchaks, chloride-type orthic solonchaks, bog solonchaks, magnesium solonetz, sulphate-type dry solonchaks, chloride-sulfate-type dry solonchaks, and sulphate – chloride -type dry solonchaks. Thus, there are 39 soil species of saline soil with an area of 102.38 million hm^2, representing over 1/4-1/5 of the land area in Gansu Province (Gansu soil 1993). The salinized soils were mainly classified as sulfate-type and chloride-sulfate-type saline soils, which accounted for 37.9% and 35.3% of the total area of saline soil, respectively, followed by sulfate-chloride-type saline soil (22.2%). Less common saline soils include Chloride-type (2.2%), magnesian alkalization type (1.4%) and complex type (1%). The ecological environment in the saline soil areas is fragile, and the ecosystem needs to be carefully managed and restored.

Halophytes play an important role in maintaining the vulnerable ecosystems of arid and salinized regions. Soil seed banks represent a memory of past and present vegetation, largely regulate the regenerative potential of species reproducing by seed (Gioria & Pyšek, 2016), and play critical roles in restoring degraded vegetation and ecosystem in desertification regions (Zhan *et al*., 2007; Williams *et al*., 2010). In saline soil in arid areas with evapotranspiration rates higher than precipitation rates, soil moisture is a major factor to control seed germination and determine the distribution patterns of species (Shen *et al*., 2015). Salinity is another crucial factor for the establishment of plants (Gorai & Neffati 2007). Germination failure in saline soils is often caused by high salt concentrations because of the accumulation of salts in the soil surface with high rate of evaporation (Gorai *et al*., 2014). Thus, knowledge of the impact of halophytes on the seed bank is essential to predict future plant population and community dynamics.

The feasibility of vegetation restoration using the soil seed bank is largely dependent on its seed density (Duncan *et al*., 2009) and species composition. It has been proven that these can be affected by many factors, such as seed size and quality (Gonzalez & Ghermandi, 2012), microsite and litter cover (Farrell *et al*., 2012), microhabitat variation (Gomaa 2012), human disturbance (Li *et al*., 2017), historical vegetation (Sanderson *et al*., 2014), diversity (Hager *et al*., 2015), and species distribution (Gulshan *et al*., 2013). There has been little research on the relationship in species composition between the soil seed bank and aboveground vegetation, and saline soil seed density of 5 subtypes and 13 soil genera in arid and salinized areas. The interactive effect between soil seed banks and aboveground vegetation are not well known either. The objectives of this study were to investigate the species composition of aboveground vegetation and soil seed bank, and the quantity and spatial distribution of the soil seed banks on 5 soil subtypes and 13 soil genera in arid and salinized areas of Gansu Province.

Materials and Methods

Study area: The study area was located in the Hexi Corridor of northwestern Gansu Province, China (37°17′-42°48′N, 92°12′-103°48′E) and influenced by continental climate and Tibetan Plateau climate. The region is characterized with hot dry summers and cold dry winters and has an annual precipitation of 30 to 160 mm from July to September. The annual average temperature was 7°C, annual evaporation 2000-3000 mm, altitude between 1100 m and 1500 m, and frost-free days between 160 and 230 days. The soil was a typical saline-sodic badland.

Sampling sites and measurement of aboveground vegetation: Based on the results of the second soil survey in Gansu Province, 5 sub classes and 13 soil genera were determined and three typical samples were chosen for each soil genus (Fig. 1). A uniform plot with sound topographic conditions was selected and two 10 m long parallel sampling lines 5 m apart were established. A 10 cm◊10 cm quadrat was placed every 3 m along each of the transects. Plant species, quantity, plant height and coverage of each quadrat were recorded, and the position of quadrats was determined by GPS (Table 1).

Species composition of saline soil seed banks: Seed banks can be divided into three categories: transient, short-term persistent and long-term persistent (Thompson *et al*., 1997). Soil samples were taken with a soil sampler (the volume of 10 cm×10 cm) in various depths (0-5 cm and 5-10 cm) from six randomly selected replicates in three seasons in 2015. Soil samples obtained in spring (25 May) contained short-term persistent and transient seed banks, in summer (25 July) mainly contained long-term persistent seed banks, in autumn (25 October) contained new seeds as well as long-term persistent seeds in 2015. The soil samples were packed in soil bags, labeled, brought back to the laboratory, and dried to prevent seed germination. The composition of the soil seed banks were determined by germinating all seed from the samples as described below:

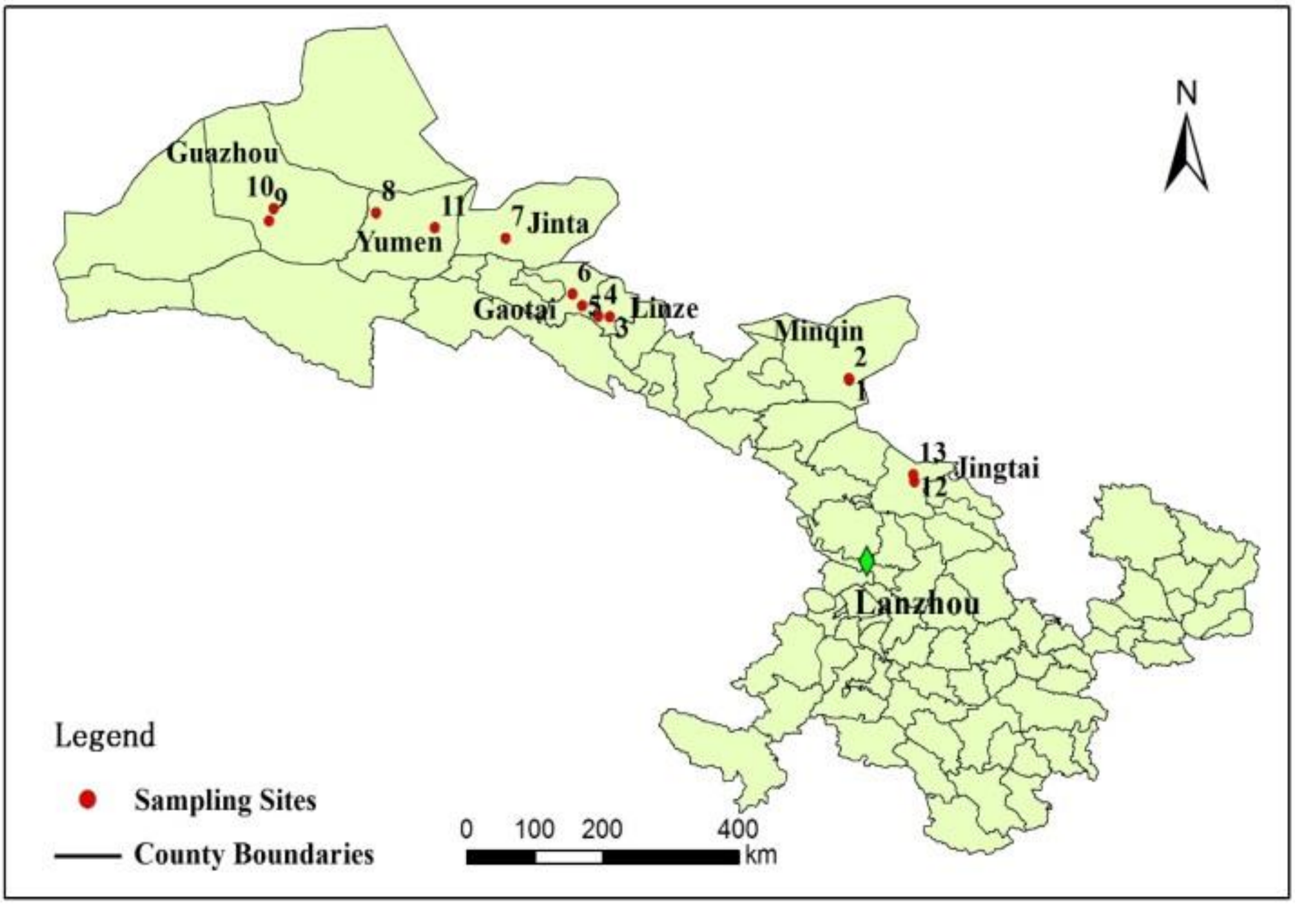

Fig. 1. Distribution of the sampling sites of 5 subtypes and 13 genera in arid and salinized areas of Gansu Province, China.

Table 1. Site description of 5 subtypes and 13 genera in the arid regions of northwest China.

Solonchak type	Soil genus	No. and sampling points	longitude	latitude	Altitude /m	Annual evaporation/mm	Annual rainfall /mm	Groundwater level /m
Meadow solonchaks	Chloride-type meadow solonchaks	3/Linze county	39°12′18″	100°07′45″	1412	1830.4	118.40	0.70-1.2
	Sulfate-chloride-type meadow solonchaks	2/Minqin county	38°26′57″	103°17′20″	1355	2644	110.00	0.8-1.2
	Chloride-sulfate-type meadow solonchaks	4/Linze county	39°12′58″	99°58′37″	1417	1830.40	118.40	1.5-1.8
	Sulphate-type meadow solonchaks	5/Gaotai county	39°20′36″	99°45′42″	1355	1923.00	112.30	2.0-2.5
Orthic solonchaks	Chloride-type orthic solonchaks	12/Jingtai county	37°11′04″	104°09′13″	1556	3000	185.00	1.2-1.5
	Sulfate-chloride-type orthic solonchaks	11/Yumen city	40°18′24″	97°48′40″	1227	3300	79.00	2.0-2.5
	Chloride-sulfate-type orthic solonchaks	6/Gaotai county	39°29′30″	99°37′52″	1326	1923.00	112.30	1.2-1.5
	Sulfate-type orthic solonchaks	13/Jingtai county	37°15′49″	104°08′23″	1560	3000	185.00	1.0-1.5
Bog solonchaks	Chloride bog solonchaks	1/Minqin county	38°25′40″	103°17′56″	1360	2644	110.00	0.5-1.0
Alkalinzed solonchaks	Magnesium solonetz	8/Yumen city	40°29′17″	97°02′13″	1385	2952	63.30	1.0-1.5
Dry solonchaks	Sulfate-chloride-type dry solonchaks	7/Jingta county	40°10′33″	98°44′41″	1233	2538.60	59.90	3.0-4.0
	Chloride-sulfate-type dry solonchaks	9/Guazhou county	40°23′07″	95°36′54″	1138	3140.60	45.30	5.0-6.0
	Chloride type-dry solonchaks	10/Guazhou county	40°32′26″	95°40′35″	1154	3140.60	45.30	4.0-5.0

Table 2. Distribution and percentage of saline seed bank density (seeds/m^2) at 0-5 cm and 5-10 cm soil depths among 5 subtypes and 13 genera in arid regions of northwest China.

Solonchak type	Soil genus	0-5cm soil layer						5-10cm soil layer						Chi-Square Test	*P*
		Spring	Seed density percentage	Summer	Seed density percentage	Autumn	Seed density percentage	Spring	Seed density percentage	Summer	Seed density percentage	Autumn	Seed density percentage		
Meadow solonchaks	Chloride-type	258.30±132.7	82.01	194.43±136.6	64.21	58.35±42.9	50.02	56.68±67.8	17.99	108.35±47.1	35.79	58.30±75.0	49.98	0.000	1.000
	Sulfate-chloride-type	50.00±93.9	59.99	362.50±52.4	87.88	58.30±75.0	58.31	33.35±72.0	40.01	50.00±53.8	12.12	41.68±65.8	41.69	0.667	0.955
	Chloride-sulfate-type	58.35±97.9	77.75	45.83±62.2	61.08	275.00±37.0	73.33	16.70±40.8	22.25	29.20±36.1	38.92	100.00±58.9	26.67	0.000	1.000
	Sulphate-type	50.00±93.2	74.96	183.35±49.1	63.77	106.68±43.9	58.18	16.70±40.8	25.04	104.18±47.7	36.23	76.68±43.5	41.82	0.000	1.000
Orthic solonchaks	Chloride-type	304.20±110.0	52.77	91.68±40.5	58.92	70.85±63.8	100.00	272.23±163.8	47.23	63.92±45.4	41.08	0	0	0.000	1.000
	Sulfate-chloride-type	33.30±51.60	50.00	33.30±81.6	66.6	66.70±63.3	79.98	33.30±81.6	50.00	16.70±40.8	33.40	16.70±40.8	20.02	1.000	0.607
	Chloride-sulfate-type	27.77±58.0	62.45	66.70±163.3	66.7	54.18±47.1	68.43	16.70±40.8	37.55	33.30±51.6	33.30	25.00±46.2	31.57	0.000	1.000
	Sulfate-type	291.65±68.2	84.54	791.70±80.5	54.91	344.47±62.6	67.4	53.35±82.8	15.46	650.00±224.0	45.09	166.65±88.6	32.6	0.000	1.000
Bog solonchaks	Chloride-type	346.03±113.6	87.37	91.65±190.7	84.59	529.15±46.3	95.49	50.00±32.5	12.63	16.70±40.8	15.41	25.00±61.2	4.51	0.000	1.000
Alkalinzed solonchaks	Magnesium solonetz	33.30±81.6	66.6	33.35±81.7	66.63	66.70±77.4	79.98	16.70±40.8	33.4	16.70±40.8	33.37	16.70±40.8	20.02	2.000	0.572
Dry solonchaks	Sulfate-chloride-type	85.43±130.3	61.19	70.85±52.9	61.44	191.67±52.2	85.18	54.18±76.4	38.81	44.47±33.8	38.56	33.35±49.1	14.82	0.000	1.000
	Chloride-sulfate-type	16.70±40.8	50.00	41.70±52.1	62.52	50.00±83.7	59.99	16.70±40.8	50.00	25.00±46.2	37.48	33.35±31.7	40.01	0.667	0.955
	Chloride-type	233.30±54.1	87.49	16.70±40.8	100	45.85±54.8	100.00	33.35±81.7	12.51	0	0	0	0	0.667	0.955

Germination of soil seed and species identification: Species in the soil seed banks were determined using a modified seed germination and emergence method. Due to high salt content and compaction of the soil, the following procedures/steps were adopted to improve the germination conditions. The first step was to resolve the compacted salinized soil of samples. After rocks and litter were picked out, soil samples were then weighed on a scale and put in a plastic box. Tap water (water-soil ratio ranging from 10:1 to 1:1) was added and stirred with a glass stick for 3-5 min. Then 50-100 mL of 0.5 N $(NaPO_3)_6$ was added, stirred for 1 min with a glass stick, and allowed to stand still for 3-4 h. The second step was to rinse the soaked soil from the seeds. Four sieves with different apertures sizes (2 mm, 1 mm, 0.25 mm, and 0.075 mm) were used and arranged from top (2-mm sieve) to bottom (0.075-mm sieve). The soaked samples in plastic boxes were then poured through the sieves, which were rinsed repeatedly with tap water. After large gravels were picked out, the residue including seeds from the sieves were collected. The seed was then grown in pots for germination and species identification. Each pot had a bottom diameter of about 20 cm and a depth of 5 cm, and was filled with a mixture of 8-10 cm thick peat and vermiculite (ratio = 3:1). The mixture of peat and vermiculite was pasteurized at high temperatures to kill any seeds or living organisms. The rinsed residues were.

Evenly distributed in the pots and then the mixture of peat soil and vermiculite was sprinkled on them to 1– 2 cm depth. Germination was carried out in a greenhouse at temperatures between 25°C and 30°C. Light, well-ventilated white cloth was placed above each pot to the pots were kept clean. During the period of seed germination, the culture medium was kept moist. Once a seed was germinated, it was regarded as a viable seed. The species were identified and counted and the identified plants were removed from the pots. The whole process continued until no more seedlings appeared in the pots. Considering that spring was the season of plant germination, soil samples collected were dried for 20 days and stored at low temperature to avoid seed germination and loss of viability. Germination experiments were performed for four months from March to July in the following year.

Data analysis: The Jaccard similarity index was applied to examine the similarity of species composition in the soil seed bank and aboveground vegetation (Zhang, 2004):

$$q_{jk}=c/(a+b+c) \quad (1)$$

where a is the number of the species found in Quadrat J but not found in Quadrat K; b is the number of the species found in Quadrat K but not found in Quadrat J; c is the number of the common species between seed bank and vegetation. According to the principle of Jaccard similarity, q between 0.75 and 1.00 indicates similar result, between 0.25 and 0.5 indicates the dissimilar medium, and between 0.00 and 0.25 indicates extremely dissimilar result (Tan *et al*., 2010).

Seed density was calculated as the number of seeds per unit area. Community density was calculated as the number of plants per unit area. Correlation analysis and analysis of variance were performed with SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

Results

Species composition of aboveground vegetations: In total, 21 species from 9 families and 19 genera were identified in the aboveground vegetations (Appendix 1). The 21 species included 7 species of Chenopodiaceae (33%), 6 species of Gramineae (29%), 2 species of Leguminosae (10%), and 1 species of each of the 6 families (Tamaricaceae, Zygophyllaceae, Elaeagnaceae, Asteraceae, Umbelliferae, and Solanaceae) (5%). Species in this area predominantly included Chenopodiaceae and Gramineae.

Species composition of saline soil seed banks: A total of 34 species from 31 genera and 14 families were identified from the saline soil seed banks (Appendices 2, 3, and 4). The 34 species included 9 species of Chenopodiaceae (26.47%), 5 species of Asteraceae (14.71%), 5 species of Gramineae (14.71%), 3 species of Leguminosae (8.82%), 2 species of Polygonaceae (5.88%), 2 species of Convolvulaceae (5.88%), 1 species of each of the 8 families (Zygophyllaceae, Boraginaceae, Amaranthaceae, Solanaceae, Brassicaceae, Labiatae, Ranunculaceae, and Caryophyllaceae) (23.53%). The plant species of saline soil seed banks in the arid areas of Gansu Province included Chenopodiaceae, Asteraceae, and Gramineae.

Quantitative characteristics of soil seed banks: In spring, summer, and autumn, the seed densities of the seed banks in 5 saline soil subtypes decreased in the following order: meadow solonchaks > orthic solonchaks > dry solonchaks > bog solonchaks > alkalized solonchaks (Appendices 2, 3, and 4). Depending on the soil genus, the seed density of soil seed banks varied in spring, summer, and autumn, and the mean seed densities in the 13 soil genera decreased in the following order: sulfate-type orthic solonchaks > sulfate-chloride-type dry solonchaks > sulfate-chloride-type meadow solonchaks > chloride-type bog solonchaks > chloride-type meadow solonchaks > sulphate-type meadow solonchaks > chloride-type orthic solonchaks > chloride-sulphate-type meadow solonchaks > chloride-type dry solonchaks > chloride-sulfate-type orthic solonchaks > magnesium solonetz > chloride-sulfate-type dry solonchaks > sulfate-chloride-type orthic solonchaks. In addition, seeds of species in the soil seed bank were unevenly distributed, and the densities of different plant communities in the soil seed bank showed significant differences. There were no significant differences in seed density of the soil seed banks among the 13 soil genera.

Vertical distribution of soil seed banks: The density of saline soil seed banks decreased with increasing soil depth, and the seeds were mainly distributed in the 0-5 cm soil and were 69%, 69%, and 75% of the total number of seeds in spring, summer and autumn, respectively (Table 2). Seeds in the 5-10 cm soil layer accounted for 31%, 31%, and 25% of the total number of seeds in spring, summer, and autumn, respectively.

Appendix 1. Plant density (plants/m^2) of aboveground vegetation of 5 subtypes and 13 genera in arid region of northwest China.

Family	Species	Meadow solonchaks				Orthic solonchaks				Bog solonchaks	Alkalized solonchaks	Dry solonchaks			Chi-Square Test	*P*
		Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulphate-type	Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulfate-type	Chloride-type	Magnesium solonetz	Sulfate-chloride-type	Chloride-sulfate-type	Chloride-type		
Total number of species		**5**	**3**	**5**	**4**	**1**	**3**	**5**	**7**	**5**	**4**	**6**	**3**	**2**		
The mean species density in each plot		3.35±2.8	8.86±12.0	6.07±4.4	7.15±4.5	28.69±8.3	7.56±10.3	3.67±3.7	8.57±7.5	11.82±8.1	8.64±7.2	6.70±5.8	15.56±14.6	9.27±1.4	0.00	1.000
Chenopodiaceae	*A*	–	–	3.45±1.2	–	–	–	–	–	–	–	–	–	–	9.31	0.002**
	B	3.46±3.2	22.7±5.71	4.87±3.5	–	–	–	–	3.38±0.02	21.91±8.4	–	2.39±1.2	–	–	16.62	0.011**
	C	–	–	–	–	–	–	–	3.20±0.2	–	–	–	–	–	9.31	0.002**
	D	–	–	–	–	–	–	–	14.97±10.6	–	–	–	–	–	9.31	0.002**
	E	–	–	–	–	–	–	–	10.11±4.3	–	–	–	–	–	9.31	0.002**
	F	–	–	–	–	–	–	–	–	6.78±0.1	–	–	–	–	9.31	0.002**
	G	–	–	–	–	–	–	–	–	11.23±3.5	–	–	–	–	9.31	0.002**
Gramineae	*H*	6.31±5.6	–	–	–	–	–	–	–	–	–	–	–	–	9.31	0.002**
	I	0.46±0.02	–	–	–	–	19.36±6.9	0.88±0.02	2.03±0.4	1.77±0.5	18.93±4.7	–	–	–	16.62	0.011**
	J	–	–	–	11.25±4.2	–	–	–	–	–	–	–	–	–	9.31	0.002**
	K	–	–	–	8.34±3.4	–	–	–	–	–	–	–	–	–	9.31	0.002**
	L	–	–	–	8.21±2.4	–	–	–	–	–	–	–	–	–	9.31	0.002**
	M	–	–	–	0.80±0.1	–	–	1.29±0.4	–	–	–	–	–	–	15.39	<0.001***
Leguminosae	*N*	–	–	10.42±0.6	–	–	–	9.94±2.7	–	–	6.32±3.3	3.75±1.2	–	10.29±5.2	18.85	0.002**
	O	–	–	–	–	–	–	–	–	–	2.10±1.1	–	–	–	9.31	0.002**
Compositae	*P*	–	–	–	–	–	–	–	–	–	–	16.34±7.2	32.34±2.4	–	15.39	<0.001***
Tamaricaceae	*Q*	6.00±1.0	1.44±0.02	10.79±4.7	–	28.69±8.3	2.67±2.4	4.11±2.4	4.40±0.2	–	7.20±0.1	3.65±0.7	5.99±1.3	–	3.08	0.98
Zygophyllaceae	*I*	0.54±0.02	–	0.80±0.1	–	–	0.64±0.1	2.14±0.9	–	17.39±7.6	–	11.37±7.8	8.36±9.3	8.24±4.9	9.85	0.276
Elaeagnaceae	*S*	–	2.44±0.3	–	–	–	–	–	–	–	–	–	–	–	9.31	0.002**
Umbelliferae	*T*	–	–	–	–	–	–	–	–	–	–	2.67±2.3	–	–	9.31	0.002**
Solanaceae	*U*	–	–	–	–	–	–	–	21.93±3.7	–	–	–	–	–	9.31	0.002**

Note: A- *Kalidium foliatum, B- Kalidium gracile, C- Suaeda glauca,* D- *Chenopodium album, E-Atriplex tatarica, F-Agriophyllum squarrosum, G-Haloxylon ammodendron, H-Achnatherum splendens,I- Phragmites australis, J-Agropyron cristatum, K-Agropyron mongolicum, L-Setaria viridis, M-Leymus secalinus, N-Alhagi sparsifolia, O-Glycyrrhiza uralensis, P-Karelinia caspia, Q-Tamarix ramosissima, I-Nitraria tangutorum, S-Elaeagnus angustifolia, T-Foeniculum vulgare,U- Lycium chinense*

Table 3. Similarity index of saline soil seed bank among 5 subtypes and 13 genera in arid regions of northwest China.

Solonchak type	Soil genus	Meadow solonchaks				Orthic solonchaks				Bog solonchaks	Alkalized solonchaks	Dry solonchaks		
		Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulphate-type	Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulfate-type	Chloride-type	Magnesium solonetz	Sulfate-chloride-type	Chloride-sulfate-type	Chloride type
Meadow solonchaks	Chloride-type	1.00	0.24	0.22	0.35	0.21	0.13	0.20	0.25	0.29	0.00	0.16	0.06	0.13
	Sulfate-chloride-type		1.00	0.40	0.38	0.47	0.45	0.46	0.27	0.42	0.00	0.33	0.23	0.14
	Chloride-sulfate-type			1.00	0.21	0.21	0.21	0.25	0.18	0.50	0.07	0.26	0.21	0.38
	Sulphate-type				1.00	0.41	0.20	0.24	0.24	0.27	0.07	0.25	0.13	0.19
Orthic solonchaks	Chloride-type					1.00	0.20	0.24	0.24	0.19	0.00	0.20	0.13	0.06
	Sulfate-chloride-type						1.00	0.36	0.25	0.44	0.00	0.26	0.33	0.30
	Chloride-sulfate-type							1.00	0.20	0.33	0.00	0.35	0.25	0.14
	Sulfate-type								1.00	0.23	0.00	0.13	0.15	0.23
Bog solonchaks	Chloride-type									1.00	0.10	0.32	0.18	0.40
Alkalized solonchaks	Magnesium solonetz										1.00	0.16	0.25	0.22
Dry solonchaks	Sulfate-chloride-type											1.00	0.26	0.32
	Chloride-sulfate-type												1.00	0.44
	Chloride-type													1.00

Soil seed bank differences among different soil subtypes and soil genera: Jaccard similarity coefficient between the magnesium solonetz and the other 12 soil genera was between 0.00 and 0.25, indicating the extremely dissimilar level (Table 3). The coefficient of similarity among other soil genera was between 0.13 and 0.50, indicating an extremely dissimilar or medium dissimilar level.

Relationship between soil seed banks and aboveground communities: Aboveground vegetations and soil seed banks shared less common plant species in 5 subtypes and 13 soil genera in arid areas of Gansu Province (Table 4). Jaccard similarity coefficients between soil seed banks and aboveground vegetations were between 0 and 0.333. The aboveground vegetation in sulphate-chloride-type meadow solonchaks, chloride-type orthic solonchaks, magnesium solonetz, and chloride-sulphate-type dry solonchaks did not lead to more seed of these species in the soil seed banks. Although the aboveground vegetation of 9 other genera had some contributions to the soil seed banks, these contributions were small. In addition, the number of the plant species in the aboveground community was less than that in the soil seed bank (Appendix 1, 2, 3, and 4). The similarity between the soil seed bank and aboveground community of sulphate-chloride-type orthic solonchaks was the highest (0.333) among different soil genera, followed by chloride-type dry solonchaks (0.286), sulfate-type orthic solonchaks (0.231), and chloride-type bog solonchaks (0.200). Thus, the species composition of aboveground communities and soil seed banks varied considerably in the 5 subtypes and 13 soil genera in arid areas of Gansu Province.

The density of aboveground vegetation was negatively correlated with the seed density of soil seed banks in sulphate-chloride-type meadow solonchaks (P=-0.999*) and chloride-type dry solonchaks (P=-1.000**). There was no significant difference between the density of aboveground vegetation and the seed density of soil seed banks in sulfate-chloride-type meadow solonchaks (P=0.988), chloride-type meadow solonchaks (P=-0.87), chloride – sulphate-type meadow solonchaks (P=-0.408), sulphate-type meadow solonchaks (P<0.05), chloride-type orthic solonchaks (P=-0.468), sulfate-chloride-type orthic solonchaks (P=0.583), chloride-sulfate-type orthic solonchaks (P=-0.513), sulfate-type orthic solonchaks (P=-0.276), chloride-type bog solonchaks (P=0.339), magnesium solonetz (P=-0.25), and chloride-sulfate-type dry solonchaks (P=-0.689).

Discussion

Difference in seed density of saline soil seed banks: Our results showed that soil seed density was 16.7~1633.3 seeds/m^2, which was lower than that in other studies (e.g. Zhao & Li, 2003 and Ma *et al*., 2007). For instance, Ma *et al*., (2007) reported 2,305 seeds/m^2 in Celei desert-oasis transitional zone, Zhao & Li (2003) found 1,029-19,022 seeds/m^2 in Horqin sandy land, Valkó *et al*., (2014) reported 30,104–51,410 seeds/m^2 in the alkaline grassland of Hungary, and Ma *et al*., (2014) reported 1,558 seeds/m^2 in a saline alkaline meadow in the eastern Tibetan Plateau, China. Therefore, the saline-sodic environment probably had a negative influence on the soil seed bank reserves in arid areas in China. The differences in saline seed bank density and composition were caused by various factors, such as the differences in natural climatic conditions and habitat conditions. Human disturbance such as grazing, reclamation for croplands, logging and burning, and picking black *Lycium chinense* in this study were also an important cause for the differences in the soil seed bank density and composition.

Table 4. The common species percentage and similarity index between soil seed bands and aboveground vegetations.

Solonchak type	Soil genus	No. of common species	% of common species in aboveground communities	% of common species in seed banks	Sorensen similarity index
Meadow solonchaks	Chloride-type	1	4.76	2.94	0.067
	Sulfate-chloride-type	0	0	0	0
	Chloride-sulfate-type	2	9.52	5.88	0.143
	Sulphate-type	1	4.76	2.94	0.067
Orthic solonchaks	Chloride-type	0	0	0	0.000
	Sulfate-chloride-type	2	9.52	5.88	0.333
	Chloride-sulfate-type	2	9.52	5.88	0.167
	Sulfate-type	3	14.29	8.82	0.231
Bog solonchaks	Chloride-type	2	9.52	5.88	0.200
Alkalized solonchaks	Magnesium solonetz	0	0	0	0
Dry solonchaks	Sulfate-chloride-type	2	9.52	5.88	0.09
	Chloride-sulfate-type	0	0	0	0
	Chloride-type	2	9.52	5.88	0.286

Furthermore, soil seed density decreased with increasing soil depth and the decrease was consistent with previous studies (Cao *et al*., 2014). The species in arid areas of Gansu Province are mainly herbaceous plants and the seeds of herbaceous plants are usually smaller and lighter than the seeds of shrubs and small trees. Most of the seed are scattered in the surface soil and seldom enter into deep layers. Dormant seeds, under the action of gravity, water seepage, animal activity, surface runoff, wind and other factors, may gradually enter the deep soil layer. The seeds entering the deeper layer soil would have lower seed vigor with time and they need light for germination. Therefore, the germination of seeds in deeper soil layers was low (Milberg, 1995).

Relationship between soil seed banks and aboveground vegetations: The seed bank and the aboveground vegetation are strongly linked (Olano *et al*., 2012). However, our capacity to predict the characteristics of aboveground vegetation based on the knowledge of soil seed bank or the characteristics of soil seed bank based on knowledge of aboveground vegetation is limited. There was a low similarity of species composition between the soil seed bank and the vegetation in this study, and the number of the species in the vegetation was less than that in saline soil seed banks. There were three relationships between the soil seed bank and the vegetation based on the results of this study.

Firstly, plant species such as *Phragmites australis*, *Nitraria tangutorum*, *Suaeda glauca*, *Alhagi sparsifolia*, *Setaria viridis*, *Kalidium foliatum*, *Atriplex tatarica*, and *Leymus secalinus* appeared in both aboveground vegetations and saline soil seed banks.

Secondly, some species existed in the saline soil seed banks, but they were not found in the aboveground vegetations. These species include *Leymus racemosus, Kochia scoparia*, *Lycopersicon esculentum*, *Artemisia annua*, *Portulaca oleracea*, *Convolvulus gortschakovii*, *Chenopodium glaucum*, *Ammopiptanthus mongolicus*, *Ixeridium dentatum*, *Batrachium bungei*, *Salsola passerina*, *Salsola collina*, *Calystegia hederacea*, *Ixeris polycephala*, *Halogeton glomeratus*, *Aeluropus sinensis*, *Rumex crispus, Amaranthus retroflexus, Capsella bursa-pastoris*, *Asterothamnus alyssoides*, *Thermopsis lanceolata*, *Mulgedium tataricum*, *Trigonotis peduncularis*, *Salvia splendens*, *Thylacospermum caespitosum*, and *Calligonum mongolicum*.

Thirdly, some species were common in the vegetation but not found in saline seed banks, e.g. *Kalidium gracile*, *Agriophyllum squarrosum*, *Haloxylon ammodendron*, *Achnatherum splendens*, *Agropyron cristatum*, *Agropyron mongolicum*, *Glycyrrhiza uralensis*, *Karelinia caspia*, *Tamarix ramosissima*, *Lycium chinense*, and *Elaeagnus angustifolia*. Whether and how these species had persistent soil seed banks should be further explored.

There are five possible reasons for the differences in species composition between saline soil seed banks and aboveground vegetations.

First, a lot of the seeds (species) in the soil seed bank possibly failed to germinate during the germination experiments due to the differences in environment conditions such as soil salinity, moisture, light, temperature and their interactions in the soil interface (Santo *et al*., 2014) between the greenhouse and the field, thus underestimating the species composition of saline soil seed banks (Pekas & Schupp, 2013). Second, some seeds in saline soil seed banks were not from the existing communities, but from the long-term accumulation in different successive phases of plant communities (Wang *et al*., 2015). Third, the species composition between aboveground vegetations and soil seed banks was only from a one-year survey and the growing time of different species may vary significantly. Furthermore, sampling time is an important factor influencing species composition in the soil seed bank. Thus, the species composition of vegetation may be underestimated (Ma *et al*., 2015). Fourth, the proportion of annuals and perennials differed in the soil seed bank and the vegetation. It was reported that it was common for perennials to be lacking in the soil seed bank, which led to less common species between the soil seed bank and the vegetation (Navarra & Quintana-Ascencio, 2012). Fifth, human disturbance may have also lead to species differences between the soil seed bank and the vegetation (Pol *et al*., 2014).

Appendix 2. Seed density (seeds/m^2) of the saline soil seed bank in spring 2015 at 0-5cm and 5-10 cm soil depths of 5 subtypes and 13 genera in arid region of northwest China.

Family	Species	Meadow solonchaks				Orthic solonchaks				Bog solonchaks	Alkalized solonchaks	Dry solonchaks			Chi-Square Test	*P*
		Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulphate-type	Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulfate-type	Chloride-type	Magnesium solonetz	Sulfate-chloride-type	Chloride-sulfate-type	Chloride-type		
Total number of species		6	6	4	7	7	2	4	3	5	2	9	1	2		
The mean species density in each plot		87.51±102.7	47.23±44.0	37.53±41.7	45.24±26.7	75.04±106.0	33.3±0	29.15±8.3	132.78±184.1	93.48±81.5	25±11.7	79.65±51.9	16.7±40.8	125±153.2	0.00	1.000
Chenopodiaceae	*A*	16.7±40.8	–	–	–	16.7±40.8	–	–	–	–	–	–	–	–	6.23	0.013**
	B	41.65±102.05	133.3±242.2	100.0±154.9	–	–	33.3±81.6	33.3±51.6	16.7±40.8	200.7±99.0	–	91.65±68.5	–	–	8.54	0.288
	C	–	33.3±51.6	–	–	283.4±218.4	–	–	36.65±53.2	16.7±40.8	16.7±40.8	16.7±40.8	–	–	10.46	0.033*
	D	–	–	–	–	158.4±186.2	–	–	–	–	–	–	–	–	9.31	0.002**
	E	–	–	–	–	–	–	–	345.0±194.9	16.7±40.8	–	–	–	–	15.39	<0.001***
Gramineae	*F*	183.3±194.1	–	–	66.7±163.3	–	–	–	–	–	–	–	–	–	15.39	<0.001***
	G	16.7±40.8	–	–	83.3±116.9	16.7±40.8	–	16.7±40.8	–	150.0±273.9	33.3±81.6	75.0±175.1	–	–	9.62	0.087
	H	250.0±183.9	–	–	33.3±51.6	16.7±40.8	–	–	–	–	–	–	–	–	18.69	<0.001***
	I	–	–	–	66.7±163.3		–	–	–	–	–	–	–	–	9.31	0.002**
Portulacaceae	*J*	–	33.35±122.5	–	–	16.7±40.8	–	–	–	–	–	–	–	–	15.39	<0.001***
Compositae	*K*	16.7±40.8	–	–	–	–	–	33.3±81.6	–	–	–	141.7±204.1	–	–	18.69	<0.001***
	L	–	16.7±40.8	–	–	–	–	33.3±81.6	–	–	–	141.7±200.0	–	–	18.69	<0.001***
	M	–	–	–	16.7±40.8	–	–	–	–	–	–	–	–	–	9.31	0.002**
	N	–	–	–	33.3±51.6	16.7±40.8	–	–	–	–	–	–	–	–	15.39	<0.001***
Convolvulaceae	*O*	–	16.7±40.8	–	–	–	–	–	–	–	–	–	–	–	9.31	0.002**
	P	–	–	–	–	–	–	–	–	–	–	16.7±40.8	–	–	9.31	0.002**
Zygophyllaceae	*Q*	–	50.0±83.7	16.7±40.8	–	–	33.3±51.6	–	–	83.3±204.1	–	116.7±204.1	–	233.3±122.5	16.62	0.011*
Labiatae	*I*	–	–	16.7±40.8	–	–	–	–	–	–	–	–	–	–	9.31	0.002**
Leguminosae	*S*	–	–	16.7±40.8	–	–	–	–	–	–	–	100.0±223.6	16.7±40.8	16.7±40.8	11.23	0.004**
Ranunculaceae	*T*	–	–	–	16.7±40.8	–	–	–	–	–	–	–	–	–	9.31	0.002**
Solanaceae	*U*	–	–	–	–	–	–	–	–	–	–	16.7±40.8	–	–	9.31	0.002**

Note: A- *Chenopodium album, B- Kochia scoparia, C- Chenopodium glaucum,* D- *Salsola passerina , E-* Suaeda glauca, *F- Leymus secalinus, G- Phragmites australis, H- Artemisia annua,I- Leymus secalinus, J- Portulaca oleracea, K- Ixeris polycephala , L- Ixeris polycephala, M- Ixeridium dentatum, N- Artemisia annua, O- Convolvulus gortschakovii, P- Calystegia hederacea, Q- Nitraria tangutorum, I- Salvia splendens, S- Ammopiptanthus mongolicus, T- Batrachium bungei,U- Lycopersicon esculentum.*

Appendix 3. Seed density (seeds/m^2) of the saline soil seed banks in summer 2015 at 0-5cm and 5-10 cm soil depths of 5 subtypes and 13 genera in arid region of northwest China (seeds /m^2).

Family	Species	Meadow solonchaks				Orthic solonchaks				Bog solonchaks	Alkalized solonchaks	Dry solonchaks			Chi-Square Test	*P*
		Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulphate-type	Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulfate-type	Chloride-type	Magnesium solonetz	Sulfate-chloride-type	Chloride-sulfate-type	Chloride-type		
Total number of species		4	5	6	5	7	1	1	5	3	3	5	3	1		
The mean species density in each plot		172.91±76.2	286.67±427.7	37.52±33.2	96.7±117.5	58.36±90.2	25.0±40.8	50±51.6	531.3±697.7	60.67±60.1	27.8±19.2	68.35±84.7	36.13±26.8	16.7±40.8	0.00	1.000
Chenopodiaceae	*A*	—	—	—	—	—	—	—	—	—	—	—	—	16.7±40.8	9.31	0.002**
	B	—	—	25.0±41.6	16.7±40.8	66.65±51.6	—	—	1633.3±497.7	16.7±40.8	16.7±40.8	16.7±40.8	16.7±40.8	—	7.39	0.117
	C	150.0±320.9	16.7±40.8	—	16.7±40.8	—	—	—	33.3±81.6	—	—	—	—	—	13.77	0.003**
	D	150.0±281.1	1133.3±958.2	50.0±101.3	—	16.7±40.8	—	—	—	50.0±54.8	—	216.7±483.4	—	—	13.31	0.021*
	E	—	—	—	—	16.7±40.8	—	—	425.0±275.7	—	—	—	—	—	15.39	<0.001***
	F	—	—	—	—	258.4±282.8	25.0±40.8	—	—	—	—	—	—	—	15.39	<0.001***
Gramineae	*G*	108.35±163.3	—	—	—	—	—	—	—	—	—	—	—	—	9.31	0.002**
	H	—	183.3±325.1	100.0±244.9	—	—	—	—	16.7±40.8	—	50.0±122.5	33.3±81.6	—	—	18.85	0.002**
	I	283.3±694.0	—	—	300.0±57.3	—	—	—	—	133.3±326.6	—	—	—	—	18.69	<0.001***
	J	—	16.7±40.8	—	66.7±163.3	—	—	—	—	—	—	—	66.7±163.3	—	11.23	0.004**
Amaranthaceae	*K*	—	—	—	—	16.7±40.8	—	—	—	—	—	—	—	—	9.31	0.002**
Portulacaceae	*L*	—	—	16.7±40.8	—	—	—	—	—	—	—	—	—	—	9.31	0.002**
Compositae	*M*	—	—	—	—	16.7±40.8	—	—	—	—	—	—	—	—	9.31	0.002**
Zygophyllaceae	*N*	—	83.35±75.3	—	—	—	—	50.0±51.6	—	—	—	58.35±70.8	—	—	18.69	<0.001***
Leguminosae	*O*	—	—	16.7±40.8	—	—	—	—	—	—	16.7±40.8	16.7±40.8	25.0±51.6	—	8.00	0.018*
	Q	—	—	16.7±40.8	—	—	—	—	—	—	—	—	—	—	9.31	0.002**
Caryophyllaceae	*I*	—	—	—	—	16.7±40.8	—	—	16.7±40.8	—	—	—	—	—	6.23	0.013*
Polygonaceae	*S*	—	—	—	83.3±204.1	—	—	—	—	—	—	—	—	—	9.31	0.002**

Note: A- *Kochia scoparia*, B- *Chenopodium glaucum*, C- *Halogeton glomeratus*, D- *Salsola passerina*, E- *Suaeda glauca*, F- *Kalidium foliatum*, G- *Leymus secalinus*, H- *Phragmites australis*,I- *Aeluropus sinensis*, J- *Setaria viridis* , K- *Amaranthus retroflexus*, L- *Portulaca oleracea*, M- *Ixeris polycephala*, N- *Nitraria tangutorum*, O- *Alhagi sparsifolia*, P- *Thermopsis lanceolata*, Q- *Thermopsis lanceolata*, I- *Thylacospermum caespitosum*, S- *Rumex crispus*.

Appendix 4. Seed density (seeds/m^2) of the saline soil seed banks in autumn at 0-5cm and 5-10 cm soil depths of 5 subtypes and 13 genera in arid region of northwest China.

Family	Species	Meadow solonchaks				Orthic solonchaks				Bog solonchaks	Alkalized solonchaks	Arid solonchaks			Chi-Square Test	*P*
		Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulphate-type	Chloride-type	Sulfate-chloride-type	Chloride-sulfate-type	Sulfate-type	Chloride-type	Magnesium solonetz	Sulfate-chloride-type	Chloride-sulfate-type	Chloride-type		
Total number of species		3	4	4	7	4	3	5	4	4	4	9	3	4		
The mean species density in each plot		55.57±34.7	70.84±97.5	120.8±164.6	70.26±91.5	70.85±87.5	50.03±57.7	46.68±36.1	175.03±186.0	347.9±295.9	35.45±37.5	114.82±150.1	38.9±19.2	45.85±47.9	0.00	1.000
Chenopodiaceae	*A*	83.3±68.3	216.65±87.2	366.5±72.4	16.7±40.8	—	—	100.0±44.9	—	616.7±50.9	—	250.0±68.2	—	—	13.46	0.062
	B	—	16.7±40.8	—	16.7±40.8	50.0±83.7	16.7±40.8	—	375.0±76.1	—	—	33.3±51.6	—	16.7±40.8	8.15	0.086
	C	—	16.7±40.8	—	266.7±50.3	16.7±40.8	—	—	—	—	—	—	—	—	11.23	0.004**
	D	—	—	—	—	200.0±89.9	—	—	—	—	—	—	—	—	9.31	0.002**
	E	—	—	—	—	—	—	—	16.7±40.8	—	—	—	—	—	15.39	<0.001***
	F	—	—	—	—	—	—	—	—	—	—	16.7±40.8	50.0±83.7	—	9.31	0.002**
Gramineae	*G*	66.7±63.3	—	50.0±22.5	83.35±63.3	—	—	—	—	—	—	—	—	—	18.69	<0.001***
	H	—	33.3±81.6	—	16.7±40.8	—	116.7±85.8	—	—	158.3±57.7	—	—	—	—	19.69	<0.001**
	I	—	—	—	75.0±22.5	—	—	—	—	—	16.7±40.8	83.3±66.9	—	116.7±85.8	19.69	0.001***
	J	—	—	—	—	16.7±40.8	16.7±40.8	16.7±40.8	—	—	—	66.7±63.3	—	—	8.00	0.018*
Cruciferae	*K*	16.7±40.8	—	—	—	—	—	—	—	—	—	—	—	—	9.31	0.002**
Leguminosae	*L*	—	—	50.0±42.5	—	—	—	—	—	—	91.7±40.8	—	50.0±22.5	33.3±51.6	13.77	0.003**
	M	—	—	—	—	—	—	—	—	33.3±81.6	—	—	—	—	9.31	0.002**
Portulacaceae	*N*	—	—	16.7±40.8	—	—	—	—	—	—	—	—	—	—	9.31	0.002**
Polygonaceae	*O*	—	—	—	16.7±40.8	—	—	—	16.7±40.8	—	—	—	—	16.7±40.8	3.77	0.052
	P	—	—	—	—	—	—	—	—	—	—	66.7±10.3	—	—	9.31	0.002**
Zygophyllaceae	*Q*	—	—	—	—	—	—	66.7±21.1	—	583.3±19.0	—	—	—	—	15.39	<0.001***
Amaranthaceae	*I*	—	—	—	—	—	—	16.7±40.8	—	—	16.7±40.8	—	16.7±40.8	—	3.77	0.052
	S	—	—	—	—	—	—	—	291.7±60.2	—	—	—	—	—	9.31	0.002**
Asteraceae	*T*	—	—	—	—	—	—	33.3±51.6	—	—	—	33.3±51.6	—	—	6.23	0.013*
	U	—	—	—	—	—	—	—	—	—	16.7±40.8	16.7±40.8	—	—	6.23	0.013*
Boraginaceae	*V*	—	—	—	—	—	—	—	—	—	—	466.7±48.2	—	—	9.31	0.002

Note: A- *Salsola collina*, B- *Chenopodium glaucum*, C- *Halogeton glomeratus*, D- *Kalidium foliatum*, E- *Atriplex tatarica*, F- *Kochia scoparia*, G- *Leymus multicaulis*, H- *Phragmites australis*,I- *Aeluropus sinensis*, J- *Setaria viridis* , K- *Capsella bursa-pastoris*, L- *Alhagi sparsifolia*, M- *Thermopsis lanceolata*, N- *Portulaca oleracea*, O- *Rumex crispus*, P- *Calligonum mongolicum*, Q- *Nitraria tangutorum*, I- *Amaranthus retroflexus*, S- *Suaeda glauca*,T- *Asterothamnus alyssoides*, U-*Mulgedium tataricum*, V-*Trigonotis peduncularis*

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