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Short Communication

Soil Seed Banks and Forest Succession Direction Reflect Soil Quality in Ziwuling Mountain, Loess Plateau, China

The paper presents a study by taking the soil seed banks and vegetation successions of the forests in Ziwuling Mountain as indicators to analyze the effects of the ages, and the litter layers and soil depths at growing locations in seven types of forest communities on their seed bank formations and soil quality. The results showed that the seed banks at different growing locations in the communities increased in the order of upper slope, middle slope, and lower slope; the seed storages of the seed banks in the different layers of the communities varied, much more higher in the litter layers than in 0–15 cm, and the seed storages of the seed banks in the seven types of forest communities ranked in the increasing order of *Pinus tabulaeformis* forest, *Pinus shenkaneusis* forest, *Quercus liaotungensis* forest, *Populus davidiana* forest, *Betula platyphylla* forest, scrub communities, and grassland communities; in the meantime, the seed storage of seed banks peaked in 30–50 years old *P. shenkaneusis* forest, 30–40 years old *P. tabulaeformis* forest, 15–30 years old *Q. liaotungensis*, and *P. davidiana* and *B. platyphylla* forests, and 10–15 years old scrub and grassland communities, and the ages of the communities varied with the seed storages of the seed banks in a significantly correlative manner following a fitted exponential equation. In addition, the soil seed banks of the seven types of communities consisted of rich and diverse species with the herbaceous and shrub species greatly outnumbering the arbor species; in general, the coniferous forests were composed of 31 kinds of plants, the deciduous and broadleaf forests consisted of 20–29 plant species, the shrubs contained 27 plant species, and the herbaceous plants numbered 20 plant species; The various species compositions contained only 4–6 arbor species with most being foreign species. In each of the compositions, *Bothriochloa ischemum* was the grassland plant with the highest occurrence frequency, *Sophora viciifolia* and *Hippophae reamnoides* were the shrub plants with the highest occurrence frequencies, and *Q. liaotungensis* was the arbor plant with the highest occurrence frequency, and they followed by *P. shenkaneusis* and *P. tabulaeformis*. These results showed that soil seed banks and forest successions are better indicators for soil quality from natural successions.

Keywords: Coniferous forest; Semi-arid region; Soil quality; Vegetation succession

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1 Introduction

Vegetations suffer severe degeneration in arid and semi-arid regions of western China, which results in not only a large area of damaged environment but also damaged vegetations and soil seed banks. The forests in Ziwuling Mountain, located in the hinterland of the Loess plateau in China, are the natural secondary forests better developed and conserved on loess and of great significance to regulating the climate in the west of China and maintaining ecological balance; and the forests are seed sources of great importance for rehabilitating the vegetations in the west of China and the Loess plateau by wind, animal, and water dispersal. In the recent 20 years, the boundaries of the forests has been expanding outward at 1.2–1.5 m/year, leaving a clear track of farming-abandoned land → short-term grassland → long-term grassland → grass and shrub communities → scrub communities → sparsely distributed broadleaf forests. In addition, the population of Ziwuling Mountain emigrated in great quantities in 1866 because of chaos caused by war and the abandoned land naturally recovered to the currently existing secondary forests [1, 2]. As a result, there has existed a relatively complete consequent sere of herb communities (*Bothriochloa ischemum*, *Artemisia giraldii*, and *Artemisia sacrorum*) and grass and shrub communities → scrub communities (*Sophora viciifolia*, *Hippophae ream-*

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noides, and *Ostryopsis davidiana*) → arbor and shrub mixed communities → arbor forest communities (*Pinus shenkaneusis*, *Pinus tabulaeformis*, *Quercus liaotungensis*, *Populus davidiana*, and *Betula platyphylla*) in the recent 150 years. Therefore, studying the formation and variation of the soil seed banks of forest vegetations is of great significance to natural renewal of forest vegetations, successions of dominant communities, and quick recovery of vegetations. The studies about the soil seed banks of forest vegetations can reflect community histories and play an important role in rehabilitating degenerated forest eco-systems [3, 4], thus soil seed banks are thought as the material basis for natural renewal of vegetations [5–10] and studies about soil seed banks are part of biodiversity research; and the seeds with long life span in soil seed banks are of genetic importance and thus is considered as the potential supplier of gene diversities in plant communities [11–15]; accordingly, soil seed banks are of importance in maintaining ecological diversities of populations and communities [16] and that the problems about soil seed banks are widely concerned in the research about the ecology of plant populations by restorative ecologists at home and abroad. In the recent 20 years, the research about soil seed banks has been a vibrant research field abroad [17]. Now, domestic and international reports about soil seed banks are mainly focusing on the studies about soil seed banks of natural forests in humid and semi-humid regions and fewer research reports are dealing with the studies about soil seed banks of natural secondary forests in semi-arid regions.

Research about soil seed banks started as early as 1930s when Milton of Britain began studying the quantitative compositions of soil seed banks of salina and arable lands in 1939 [18]; Olmstead et al. of America began to studying the sampling methods of soil seed banks in 1947 [19]; Burrel (1965), Major and Pyott [10], and Grant [20] of America and New Zealand studied species germinations and seasonal changes of soil seed banks in natural grasslands in1950–1960s [19–21]; Marquis [21], Thompson and Grime [22], Keddy and Reznicek [8], and Partridge of Canada, Japan, and New Zealand successively conducted the studies about species diversities and seed vitalities of soil seed banks in forests, grasslands, desert lands, and moorlands in 1970–1980s [23–25]. O'Connor and Pickett and Ghermandi and Francisco successively conducted the studies about the similarities among soil seed bank compositions and above-ground vegetation communities of tropical sparsely colonized meadows, meadows, and wild lands in Europe and South America in 1990–2000s [13, 14, 22–28]. This study presented in the paper sampled 100 soil samples for 1000-m^3 area each of which was 500 mL in its forest–land experiment to conduct the statistical analysis of soil seed banks of the forests and its result will be of significance to natural recovery and vegetation successions of the forests in semi-arid regions.

2 Materials and methods

2.1 Brief description of the region under study

Ziwuling Mountain, standing at E108°10′–109°08′ and N35°03′–36°37′, is located in the hinterland of the loess plateau and belongs to the region with natural secondary mixed needle-leaf and broad-leaf forests. The experiment was conducted in Heshangyuan Forest Farm under the administration of Qiaobei Bureau of Forestry of Shaanxi province and Lianjiabian Forest Farm of Heshui General Forest Farm of Gansu province. It was a hilly and gully region of the loess plateau whose altitude above sea level and relative height difference are generally 1500 m and about 200 m, respectively; its annual temperature, annual rainfall, accumulative temperature equal to and above 10°C, frost-free period are 7.4°C, 587.6 mm, 2671.0°C, and 112–140 days on average. Its southern-facing slopes differ from its northern-facing slopes in water and warm and its climate shows an unremarkable vertical variation [25]. This area soils are light black Lu and loessal soil developed from primitive or secondary loess mother materials, their depths evenly range within 50–130 m and there exists red earth consisting of calcareous cinnamon soil below these depths [23, 25, 26]. There has round-shaped mountain shapes whose northern-facing slopes and hilltop have smooth, gentle surfaces and whose sunny and semi-sunny slopes are sharp and which belongs to loess-covered forest steppes falling into the category of temperate-cold semi-arid regions. There is a uniformed forest forms, rich species and a forest-canopy density ranging within0.80–0.95. Its major plants are *B. ischemum*, *A. giraldii*, *A. sacrorum*, *Stipa bungeana*, *S. viciifolia*, *H. reamnoides*, *O. davidiana*, *P. shenkaneusis*, *P. tabulaeformis*, *Q. liaotungensis*, *P. davidiana*, and *B. platyphylla*.

2.2 Experimental design

The study was conducted in Heshanyuan Forest Farm and Lianjiabian Forest Farm, locating in Ziwuling Mountain and its sampling were carried out once every 3 years (1983–2003) and thus the sampling periods totaled seven. The soil samples were taken in seven types of communities, *P. shenkaneusis* forest, *P. tabulaeformis* forest, *Q. liaotungensis* forest, *P. davidiana* forest, *B. platyphylla* forest, scrub communities, and grassland community, and the sampling sites were chosen on upper, middle, and lower half-northern-facing and half-southern-facing slopes.

2.3 Sampling methods

The samples of soil seed banks were generally taken when plants began to germinate in the measurement years. According to the results of the study conducted by Bigwood in 1988, the sampling method with a large number of samples and small sampling squares is more reliable. So this study adopted this method to sample. Two groups of typical sampling locations were chosen for each type of the communities and one location in each group was set up as the permanent sampling location of 100 hm^2; and then the squares of 30 cm × 30 cm were chosen in the locations every 20 m by horizontal line transect method and they had six replicates. Soil drilling samplers were employed to sample in the litter layers and soil layers of the squares and soil sampling was conducted in four soil layers, 0–2.5, 2.5–5.0, 5.0–10, and 10–15 cm.

2.4 Lab seed counting

Two methods were adopted to count the seeds of the soil seed banks. One method is called Mechanical Sorting. This method is that seeds were mechanically sorted and counted under the microscope from soil samples. The other is named Physical Separation. According to Grime [14] in the forest area using physical methods of separation determination, this method use soil-grading sieves which were used to rinse soil samples in water-filled containers for seeds to precipitate and then the precipitated seeds were counted. In order to compare with the former experiment results, this study adopts the second method.

2.5 Seed vitality appraising

Two methods were adopted to appraise the vitalities of the seeds obtained by mechanical sorting and physical separation. The first method is seed germination: Seeds were put in Petri dishes to germinate at room temperature. The second is visual observation: Seed embryos were directly observed with anatomical lens and microscopes to inspect their freshness, oiliness, and juice for determining their vitalities. This method was identical with the methods adopted by Thompson and Grime [22], Xiong et al. [29], Wang and Yang [22, 28]. In this paper, we adopted the first method because of its easy counting and comparison with previous.

2.6 Data processing

The large quantities of the obtained data were processed and analyzed with SPSS11.0 of DPS.

3 Results

3.1 Changes of the seed densities in different layer of the soil seed banks in the forests

Measured seed densities at soil depths in the forests with different ages in Ziwuling Mountain are presented in Tab. 1. Table 1 indicates that the seed densities of the soil seed banks in the forests with different ages appeared the highest in the litter layers, the second highest in 0–5 cm soil, and the lowest in 6–10 cm soil and 11–15 cm soil. The seed densities of the soil seed banks varied with the locations of the location of stand growth, decreasing in the order of upper slope, middle slope, and lower slope, because of surface runoff and wind; in *P. shenkaneusis* and *P. tabulaeformis* forests on upper slope, the seed storages in the litter layers ranging within 2–5 cm in thickness covered 49.93–56.94% of the total seed storages of the soil seed banks, and the seed storages in 0–5 cm soil covered 38.65–48.19% of the total seed storages of the soil seed banks, but the seed storages in 6–15 cm soil covered only 1.9–4.4%; in *Q. liaotungensis*, *P. davidiana*, and *B. platyphylla* forests on upper slope, the seed storages in the litter layers ranging within 2–4 cm made up 42.24–61.68% of the seed storages of the soil seed banks, and the seed storages in 0–5 cm soil made up 36.45–41.38% of the seed storages of the soil seed banks, but the seed storages in 6–15 cm soil made up only 1.9–16.38%; in the shrubs and grassland communities on upper slope, the seed storages in the litter layers ranging within 0.56–2 cm in thickness made up 32.43–38.73% of the seed storages of the soil seed banks and the seed storages in 0–5 cm soil occupied 48.65–55.41%, but the seed storages in 6–15 cm soil occupied only 12.16–12.61%. In *P. shenkaneusis* and *P. tabulaeformis* forests on middle slope, the seed storages in the litter layers ranging within 3–6 cm in thickness accounted for 51.22–59.42% of the seed storages of the soil seed banks and the seed storages in 0–5 cm soil accounted for 37.38–47.33% of the seed storages of the soil seed banks, but the seed storages in 6–15 cm accounted for soil only 1.44–3.2%; in *Q. liaotungensis*, *P. davidiana*, and *B. platyphylla* forests on middle slope, the seed storages in the litter layers ranging within 3–5 cm made up 45.93–55.97% of the seed storages of the soil seed banks, and the seed storages in 0–5 cm soil made up 35.82–40.74% of the seed storages of the soil seed banks, but the seed storages in 6–15 cm soil made up only 8.2–13.3%; in the shrubs and grassland communities on middle slope, the seed storages in the litter layers ranging within 1.5–2 cm contained 37.50–41.86% of the seed storages of the soil seed banks and the seed storages in 0–5 cm soil contained 47.28–53.41% of the seed storage of the soil seed banks, but the seed storages in 6–15 cm soil contained only 9.1–10.85%. In *P. shenkaneusis* and *P. tabulaeformis* forests on lower slope, the seed storages in the litter layers ranging within 3–6 cm in thickness accounted for 51.74–55.02% of the seed

Table 1. Seed densities (seeds/m^2) in different layers of the soil seed banks in the different types of forest communities

Communities	Litter	Soil depth (cm)				Total
		0–2.5	2.6–5.0	6.0–10	11–15	
Upper slope						
Pinus shenkaneusis forest	345 ± 23.5	202 ± 15.2	131 ± 11.2	13 ± 2.1	0	691
Pinus tabulaeformis forest	439 ± 26.2	231 ± 16.2	67 ± 12.3	32 ± 3.6	2 ± 0.12	771
Quercus liaotungensis forest	66 ± 11.2	33 ± 8.2	6 ± 0.12	2 ± 0.12	0	107
Populus davidiana forest	55 ± 12.1	34 ± 9.3	12 ± 1.24	10 ± 1.24	3 ± 0.11	114
Betula platyphylla forest	49 ± 11.2	38 ± 8.5	10 ± 2.14	13 ± 2.44	6 ± 1.2	116
Shrub communities	43 ± 10.2	43 ± 10.2	11 ± 2.41	14 ± 3.12	0	111
Grassland communities	24 ± 5.2	26 ± 5.1	15 ± 3.2	9 ± 2.14	0	74
Middle slope						
Pinus shenkaneusis forest	356 ± 26.3	187 ± 14.2	142 ± 11.2	10 ± 2.4	0	695
Pinus tabulaeformis forest	445 ± 27.2	211 ± 12.3	69 ± 2.66	24 ± 4.2	0	749
Quercus liaotungensis forest	75 ± 6.3	40 ± 3.6	8 ± 5.2	11 ± 6.2	0	134
Populus davidiana forest	65 ± 5.2	31 ± 2.5	14 ± 4.2	9 ± 1.3	4 ± 1.2	123
Betula platyphylla forest	62 ± 4.5	43 ± 4.2	12 ± 4.1	10 ± 0.12	8 ± 2.3	135
Shrub communities	54 ± 4.2	47 ± 4.8	14 ± 2.3	13 ± 2.41	1 ± 0.11	129
Grassland communities	33 ± 2.3	31 ± 2.8	16 ± 5.2	7 ± 2.1	1 ± 0.12	88
Lower slope						
Pinus shenkaneusis forest	415 ± 23.1	231 ± 21.4	148 ± 22.3	8 ± 1.21	0	802
Pinus tabulaeformis forest	463 ± 24.1	240 ± 15.2	71 ± 12.4	22 ± 3.24	2 ± 0.14	798
Quercus liaotungensis forest	89 ± 21.1	52 ± 12.3	10 ± 3.21	21 ± 1.87	0	172
Populus davidiana forest	79 ± 12.3	36 ± 12.3	16 ± 5.62	12 ± 6.2	2 ± 1.2	145
Betula platyphylla forest	71 ± 11.2	43 ± 12.4	13 ± 3.54	16 ± 5.2	1 ± 0.14	144
Shrub communities	66 ± 14.2	65 ± 21.2	16 ± 8.12	18 ± 4.5	6 ± 1.21	171
Grassland communities	46 ± 21.0	31 ± 14.2	17 ± 5.61	10 ± 2.3	3 ± 1.3	107

storages of the soil seed banks and the seed storages in 0–5 cm soil accounted for 38.97–47.26% of the seed storages of the soil seed banks, but the seed storages in 6–15 cm accounted for soil only 0.9–3.0%; in *Q. liaotungensis*, *P. davidiana*, and *B. platyphylla* forests on lower slope, the seed storages in the litter layers ranging within 3–6 cm made up 49.31–54.48% of the seed storages of the soil seed banks, and the seed storages in 0–5 cm soil made up 35.86–38.89% of the seed storages of the soil seed banks, but the seed storages in 6–15 cm soil made up only 9.7–12.21%; in the shrubs and grassland communities on lower slope, the seed storages in the litter layers ranging within 2–3 cm contained 38.59–42.99% of the seed storages of the soil seed banks and the seed storages in 0–5 cm soil contained 44.86–47.37% of the seed storage of the soil seed banks, but the seed storages in 6–15 cm soil contained only 12.15–14.03%. In the forests of Ziwuling Mountain, the seeds of the soil seed banks mainly distributed in the litter layers, thus frequently suffering the damages by birds and rodents, becoming empty, broken, and moldy in large quantities and showing a concentrative distribution; the seed vitality was showed in seed vitality testing to be 3.42% in *P. shenkaneusis* forest, 5.03% in *P. tabulaeformis* forest, 6.91% in *Q. liaotungensis* forest, 3.11% in *P. davidiana* forest, 4.31% *B. platyphylla* forest, 2.06% in shrub communities, and 5.66% in grassland communities. The seed vitalities in soil, higher than those in the litter layers, were generally 6.67% in *P. shenkaneusis* forest, 9.21% in *P. tabulaeformis* forest, 10.12% in *Q. liaotungensis* forest, 5.39% in *P. davidiana* forest, 6.23% in *B. platyphylla* forest, 6.02% in shrub communities, and 7.05% in grassland communities, thus forming a good foundation for the succession of forest communities.

3.2 Species changes of the soil seed banks with the community ages

The numbers of the seeds naturally stored in the soil seed banks of the forests in Ziwuling Mountain were investigated with the samples collected in the forests by horizontal line transect method and the results of the seven types of forest communities, *P. shenkaneusis* forest, *Pinus tabulaeformis* forest, *Q. liaotungensis* forest, *P. davidiana* forest, *B. platyphylla* forest, shrub communities, and grassland communities are shown in Fig. 1. From Fig. 1 we can see that the seed numbers of the soil seed banks in the seven types of forest communities tended to vary in basically identical patterns, greatly increasing with increased community ages; the soil seed banks in *P. shenkaneusis* and *P. tabulaeformis* forests, increasing greatly in seed number, presented the highest seed storage and the soil seed banks of *Q. liaotungensis*, *P. davidiana*, *B. platyphylla* forests, and shrub communities presented the second high seed storages, and the soil seed banks in the grassland communities presented the lowest seed storage. *P. shenkaneusis*, a *P. tabulaeformis* variant, has been living in the forests of Ziwuling Mountain for as long as 150 years, and thus its soil seed banks has been well developed, so that great large areas of its pure natural forests have formed through the community successions by sexual reproduction of the soil seed bank; the pure forests have uniform forest forms and the renewal seedlings inside the forests presents irregular distribution and poor growth; the soil seed bank in *P. shenkaneusis* forest has three developmental stages with its age, which are: The stage at which 0–10 years old soil seed banks in 30–40 years old forests were investigated to present a stable growth; the stage at which 10–15 years old soil seed banks were investigated to greatly increase in seed number; the stage at which 15–20 years old soil seed banks were investigated to gradually decrease in seed number but in a small range, and this indicates that the seed numbers of the soil seed banks peaked at the forest age of 30–50 years and is significantly correlated with the forest age (Tab. 2). In artificial *P. tabulaeformis* forest, the soil seed bank appears to linearly and slowly increase with the forest ages, peaking at the forest age of 15–30 years, and correlated in seed storage with the forest age (Tab. 2). In *Q. liaotungensis*, *P. davidiana*, and *B. platyphylla* forests, the soil seed banks appear to stably linearly increase, peaking at the forest age of 15–30 years, and be extremely significantly correlated in seed storage with the forest ages (Tab. 2). In the shrub communities, the soil seed banks appear to slowly linearly increase with the forest age, peaking at the shrub community age of 10–15 years and significantly correlated in seed storage with the community ages (Tab. 2). In the grassland communities, the soil seed banks appear to linearly increase with the community age, peaking at the community age of 10–15 years, and correlated in seed storage with the community age (Tab. 2).

3.3 Species diversities of the soil seed banks versus forest successions in the forests

In Ziwuling Mountain, *P. shenkaneusis*, *P. tabulaeformis*, *Q. liaotungensis*, *P. davidiana*, and *B. platyphylla* forests, and shrub and grassland communities show rich species compositions in which the numbers of herbaceous and shrub species are higher that those of the arbor species and most of the species are invasive ones (Tab. 3).

It can be seen from Tab. 3 that in *P. shenkaneusis* forests, the soil seed banks presented a seed density of 767 seeds/m^2 and consisted of 31 species of which herbaceous, shrub species made up 80.65%, arbor species accounted for 19.35%, and invasive species accounted for a majority of the arbor species mainly including *P. tabulaeformis* and *Q. liaotungensis*; in *P. tabulaeformis* forests, the soil seed bank had the seed density of 787 seeds/m^2 and was composed of 31 species of which, herbaceous and shrub species covered 83.87%, arbor species occupied 16.13%, shrub species are the major invasive species, and *Q. liaotungensis* was the only arbor species; in *Q. liaotungensis* forests, the soil seed bank had a seed density of 170 seeds/m^2 and consisted of 29 plant species of which, herbaceous and shrub species covered 86.21%, arbor species covered 13.79%, herbaceous plants made up a majority of the invasive species, and arbor species included *P. tabulaeformis* and *Q. liaotungensis*; in *P. davidiana* forests, the soil seed banks had a seed density of 172 seeds/m^2 and consisted of 25 plant species of which, herbaceous and shrub species occupied 88.0%, arbor species occupies 12.0%, herbaceous plants made up a majority of the invasive species, and *Q. liaotungensis* was the major arbor species; in *B. platyphylla* forests, the soil seed banks has a seed density of 159 seeds/m^2 and were composed of 23 plants species of which herbaceous and shrub species accounted for 88.0%, arbor species accounted for 12.0%, shrub species made up a majority of the invasive species, and *Q. liaotungensis* was the major arbor species; in the shrub communities, the soil seed banks presented a seed density of 148 seeds/m^2 and contained 27 plant species of which herbaceous and shrub species occupied 85.19%, arbor species occupied 14.81%, herbaceous plants made up a majority of the invasive species, and arbor species mainly included *Q. liaotungensis*; in grassland communities, the soil seed banks had a seed density of 98 seeds/m^2, and consisted of 20 plant species of which herbaceous and shrub species accounted for 80.0%, arbor species accounted for 20.0%, shrub species made up a majority of the invasive species, and *Q. liaotungensis* was the major arbor species. In the seven types of

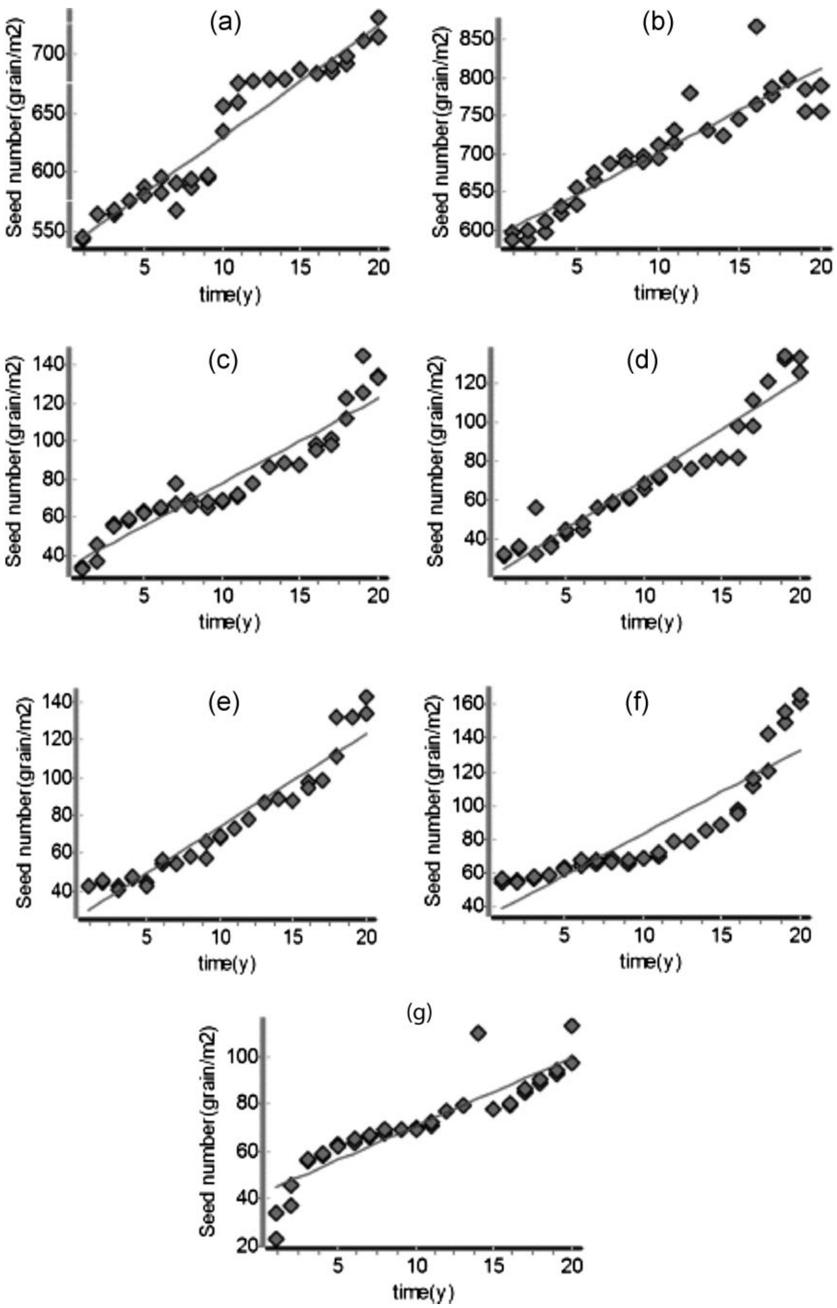

Figure 1. Seed number changes of the soil seed banks in different types of forest communities with different ages; (a) *P. shenkaneusis* forest, (b) *P. tabulaeformis* forest, (c) *Q. liaotungensis* forest, (d) *P. davidiana* forest, (e) *B. platyphylla* forest, (f) shrubs, and (g) grassland type.

Table 2. Correlation of the forest ages with the seed storages of the soil seed banks in the types of forests

Vegetation type	Linear equation	N	F	R^2	Significance level
Pinus shenkaneusis forest	$y = 591.4610 + 11.0202\ x$	40	219.006	0.8656	a)
Pinus tabulaeformis forest	$y = 535.5816 + 9.4045\ x$	40	485.733	0.9346	b)
Quercus liaotungensis forest	$y = 33.5773 + 4.4350\ x$	40	293.213	0.8961	a)
Populus davidiana forest	$y = 19.8946 + 5.0978\ x$	40	444.335	0.9289	b)
Betula platyphylla forest	$y = 24.9607 + 4.9270\ x$	40	380.545	0.9180	b)
Shrub communities	$y = 33.5865 + 4.9751\ x$	40	135.868	0.7998	c)
Grassland communities	$y = 42.1015 + 2.8643\ x$	40	154.800	0.8199	a)

a) $p < 0.01$.
b) $p < 0.001$.
c) $p < 0.05$.

Table 3. The species compositions of the soil seed banks in the types of communities (seeds/m^2)

Species	*P. shenkaneusis* forest	*P. tabulaeformis* forest	*Quercus liaotungensis* forest	*Populus davidiana* forest	*Betula platyphylla* forest	Shrub community	Grassland community
Astragalus adsurgens			3	6		3	6
Pinus shenkaneusis	402	156					
Pinus tabulaeformis	210	398	20	31	11	2	8
Quercus	35	86	41	40	33	12	3
liaotungensis	1	3	2				
Quercus acutissima	3	1	2	6	2	3	8
Artemisia capillaris	6	8	3		2	4	1
Agropyron cristatum	2	9	3				
Platycladus orientalis	2	5	2	5	6	9	3
Ostryopsis davidiana	1	1	2			2	1
Clematis angustifolia	2	2	1	1		3	1
Berberis amurensis	1	6	3	4	3	13	
Schisandra chinensis	2	5	6	2		8	5
Cotoneaster	3	6	3	3	2	1	
acutifolia	2	3	2			1	
Malus baccata	1	3	1				
Crataegus pinnetifida	2	2	6	3	8		
Prunus consociiflora	3	8	3	1	9	3	2
Prunus tomentisa	5	4	9	4	2		
Pyrus betulaefolia	3	3		3	9	6	5
Pyrus ussuriensis	1	2	1	2		6	8
Caragana jubata	2	3	6	9	9	2	
Cicer arictinum	1		3	6	1	3	3
Lespedeza dicolor			2		1	3	6
Oxytropis aciphylla		3	3		3	4	
Total plant number (species/m^2)							
	3	5	6	3	6	9	
	13	8	6	6	3	6	
	1	2	4	3			
	24	15	12	6	5	5	6
	3	8		6	11	3	3
	9	10	9	10	9	12	4
	10	7	6	1	3	10	8
	11	10		2	10	9	6
	3	3		8	11	6	10
	31	31	29	25	23	27	20
Total seeds number (seeds/m^2)	767	787	170	172	159	148	98

communities in Ziwuling Mountain, the soil seed banks show rich species compositions in which the herbaceous and shrub species greatly surpasses the arbor species; in the early stage of vegetation succession, the species compositions of aboveground vegetations and the soil seed banks have the same species and the two become differentiated in species composition as the successions continues to go on and the community coverage increase, so that their similarity goes below 30% and their invasive species increases in their quantities. Zhou Xianye et al. studied evergreen broadleaf forests in 2000 finding that the species compositions of the soil seed banks are relatively identical with the species compositions of the aboveground vegetations in the early succession stage and the two became differentiated, presenting a similarity of only 10–30%, in the other succession stages. According to the past changes of the vegetation compositions and soil seed banks in the forests of Ziwuling Mountain, it follows that in the future 50–100 year succession, pure forests consisting mainly of *P. shenkaneusis* and *P. tabulaeformis* will occur on middle-lower northward-facing and half-northward-facing slopes, and needle-leaf and broadleaf mixed forests mainly composed of *P. shenkaneusis* and *P. tabulaeformis* and *Q. liaotungensis* will appear on the upper northward-facing and half-northward-facing slopes; mixed forests with *Q. liaotungensis* as the major component and *P. tabulaeformis* in a small quantity will form on middle and lower half-southern-facing slopes and broadleaf forests mainly composed of *P. tabulaeformis* will form on upper half-southern-facing slope; but the vegetations will evolve through succession into *H. reamnoides* and *S. viciifolia* scrubs mixed vegetations including small quantities of *Q. liaotungensis* on middle and lower southern-facing slopes and shrub and grass mixed vegetations consisting of *S. viciifolia*, *B. ischemum*, and *Prunus davidiana* on upper southern-facing slope.

4 Discussions and conclusions

Studying the soil seed banks of the forest vegetations in Ziwuling Mountain is of theoretical and practical significance to ecological and environmental construction, forestation, and grass planting by farming withdrawal, and natural vegetation renewal and succession in semi-arid regions of northwest China [29–32]. This paper summarizes the position experiments over more than 20 years, revealing the year-by-year and vertical changes of the soil seed banks in the seven types of communities of the forests in Ziwuling Mountain. According to the studies conducted by Ding et al., and Kemp, etc., soil seed bank shows not only a clear vertical dynamic change but also a strong year-by-year dynamic change, and the major reason for this is that the changes in climatic factors including rainfall cause vegetation succession to move on and plants to change their fruiting periods and other things to happen [1, 2, 22, 26–28, 33, 34]. But other studies about the soil seed bank of arable land indicated that soil seed banks increases with succession. In the meantime, the seed densities of the soil seed banks in grazing-prohibiting lands, which are protected, are much higher than those in shrub forestlands; the seed densities of the soil seed banks in farmland generally surpass those in grassland, and the seed density of soil seed bank in grassland is higher than that in forest [29–37]. Researches find that while the invasive-seed quantities of shrub and herbaceous increase, the soil seed banks contain more and more seeds of annual and biannual plants; according to Holzapfel's et al. study, as the aridity increases, ground vegetations become more and more similar to soil seed banks or seed rains, and annual plants tend to increase in their proportion to total species quantities [12, 14, 30–37]. Its can be seen from the measurements of the seed density at different ages of growth and different soil depths that *P. shenkaneusis* and *P. tabulaeformis* appear to be the plants with the highest seed numbers in soil seed bank and followed by *Q. liaotungensis*. In early vegetation succession, the species compositions of aboveground vegetations have the same common species as the soil seed banks, but as the vegetation succession continues and the community coverage increase the common species are obviously different; in the structures of the seven types of communities, the arbor species with the greatest number of young seedlings is *Q. liaotungensis* and is followed by *P. shenkaneusis* and *P. tabulaeformis*, which indicates that *Q. liaotungensis* is the driving and pioneering species in natural vegetation renewal and succession in the forests of Ziwuling Mountain. These results showed that soil seed banks and vegetation succession status are better indicators for soil quality from natural vegetation, which can provide important reference for ecological restoration globally [1, 2, 28–33, 36–37].

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