Rapid revegetation by sowing seed mixtures of shrub and herbaceous species

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Abstract

Fast revegetation by means of sowing seed mixture of shrub and herbaceous species is a measure to prevent bare soils from wind and water erosion. A field experiment was used to test the effect of species selection and the ratio of shrub to herbaceous species on vegetation formation and shrub growth. Results showed that herbaceous species hastened cover formation and maintained a high coverage for longer period. However, the growth of shrubs was hindered. In North China Plain or where the soil and climate are similar, the ratio of shrub to herbaceous seeds is proposed to be 6:4~7:3 (weight ratio). Among the herbaceous species tested, *Festuca arundinacea* Schreb. grows relatively slow so it should be mixed with other fast-growing species in the practice of rapid revegetation, and a seeding density lower than 6 g • m^{-2} is proposed when applied; *Orychophragmus violaceus* O. E. Schulz. wilts when the seeds are ripe, leading to a significant decrease of coverage, so other species with different phenology should be involved when it is applied; *Viola philippica* Car. is a good ground cover plant, which grows fast and maintains a stable coverage from July to October, and a seeding density of 1.5 g • m^{-2} is proposed for rapid revegetation. Herbaceous species have different traits. Three different types of herbs were found in our experiment, i.e. slow-growing stable ground cover species (*F. arundinacea*), fast-growing unstable ground cover species (*O. violaceus*), and fast-growing stable species (*V. philippica*). Shrubs, slow-growing stable species, and fast-growing unstable species should not be used alone because they cannot cover the ground fast or they cannot maintain a long period of good coverage. A small seeding rate of fast-growing stable species should be used to ensure a fair coverage against erosion. Because natural environmental conditions are heterogeneous and stochastic, more species should be added to enhance the stability

of plant community.

KEY WORDS: rapid revegetation; seed mixture; coverage; herbaceous; shrub

1 Introduction

Development and construction projects often cause damage to native vegetation. In abandoned quarries or surface mines, recolonization of plants is very difficult (Ballesteros *et al.*, 2012) because of the destruction of natural soil structure and seed bank, as well as the limitation of nutrition and water (Jim, 2001; Haritash *et al.*, 2007). Even though technical restoration can accelerate succession, it takes decades to achieve a complex self-sustainable ecosystem (Zhang *et al.*, 2013). During the succession, wind or water erosion may occur when the vegetation coverage is still low, further decreasing soil nutrient (Zuazo & Pleguezuelo, 2008) and thus hindering the process of revegetation (Wang *et al.*, 2005). Geologic hazards may also happen if no protective measures are applied (Robbins *et al.*, 2013). Heavy metals in mineral waste may be transported by wind force and cause soil pollution (Brotons *et al.*, 2010). Besides, during construction of roads and buildings, temporary dumps without covering may be eroded, resulting in soil loss.

Soil covering is a useful measure to protect soil from wind and water erosion (Mu, 2010), where vegetation plays an important role (Sterk, 2003). The risk and intensity of wind and water erosion decrease with increased vegetation cover (Cai, 2001; Maurer *et al.*, 2009; Kefi *et al*, 2011; Houyou *et al.*, 2014). Plants increase soil surface roughness, decrease wind speed, and as a result, the erosivity and erodibility decrease (Borrelli *et al.* 2014). Plants increase concentration time during rainfall events and increase infiltration, so less runoff is produced.

Different types of vegetation respond differently to wind and water erosion. Trees with large canopy are more effective in reducing wind speed, whereas shrubs are more effective in trapping transporting materials (Leenders *et al.*, 2007). Compared to herbaceous species, shrubs have more developed root systems to improve soil structure and conserve water in deep layers, resulting in a better effect on soil and water conservation (Huang *et al.*, 2006; Wei *et al.*, 2009), and its effect is less affected by rain intensity compared to herbs (Zhang *et al.*, 2014). Trees develop slowly (Ji *et al.*, 2011), and have limited effect on soil protection during the early stage of development (Zhang & Shao, 2003), while herbs germinate and grow fast, rapidly covering the ground to prevent splash erosion and decrease runoff (Franklin, *et al.*, 2012).

Seed mixture of shrubs and grasses takes the advantage of both taxons, but the competition for light, water and nutrition may affect vegetation cover formation (Milton & Dean, 1995) and thus the effect of soil protection. As shown by some researches, the competition from grasses might cause severe growth decline of woody plants, especially during their early stage of development (Gordon, *et al,* 1989; Denslow *et al.*, 2006). Because the interaction between woody species and herbaceous species are complicated, it was proposed that traits such as niche breadth and competitiveness for different resources of different species should be thoroughly studied, and the selection of species should be based on environmental condition including soil, water and light (Heneghan *et al.*, 2008; Abe *et al.*, 2014; Oliveira *et al.*, 2014). By means of species selection and controlling seeding density, positive effect can be attained for shrub establishment (Franklin *et al.*, 2012).

In this research, measure of fast revegetation by means of sowing seed mixture of shrub and herbaceous species was tested using field experiment. We focused on: (1) which seed mixture of shrub and grass (which species and what proportion) could provide a fair or good coverage for a long period; (2) how different proportions of species affect the speed of cover formation and the stability of coverage (specifically, we tested the effect of the ratio of shrub to herbaceous seeds, $R_{s/h}$); (3) how different herbaceous species affect the growth of shrub. Based on our research, advice will be proposed on species selection and determination of their proportion in seed mixtures during the practice of revegetation in: (1) plains where wind erosion occurs, (2) gentle slopes where water erosion occurs and plant growth is not significantly affected by the slope, (3) seriously degraded sites such as abandoned mines where measures such as topsoil covering have been applied to improve soil quality.

2 Materials and methods

2.1 Study Area

The research was conducted in the Ecological Restoration Research Base of Beijing Environmental Protection Research Institute of Light Industry (EPRILI), located in Changping County, Beijing (40°9'56.73"N, 116°9'1.04"E, 57 m a.s.l.). Beijing has a continental monsoon climate with a rainy season from June to September. The mean annual precipitation is 620 mm (historical data). Monthly precipitation and average temperature during the experimental period were measured using Davis Vantage Pro2 Weather Station, and the data are shown in Figure 1.

The local soil used for the experiment was sandy loam. The pH value was 7.44. The chemical properties of the soil are shown in Table 1 (Liang, 2013).

2.2 Experimental Design

Four native species were studied, including a shrub species *Amorpha fruticosa* L, and three herbaceous species *Festuca arundinacea* Schreb., *Viola philippica* Car. and *Orychophragmus violaceus* O. E. Schulz. These species are commonly seen in North China Plain, and former researches have shown their tolerance against water or nutrient deficiency. The characters of target species are shown in Table 2 and the designs of seed mixtures are shown in Table 3.

Every design of seed mixture was tested in a 4.5-m-long, 1.3-m-wide plot, so there were altogether 40 plots. Seed mixtures with a seeding density of 15 g • m^{-2} were manually sowed without fertilizer in May 2013. Non-woven fabrics (a planar, permeable, polymeric textile material) was used as soil cover to protect the seeds from erosion and enhance humidity. Irrigation was applied until mid-June, after when precipitation became the only water source for plants.

2.3 Data Collection and Analysis

From July to October 2013, three 1×1 m^2 sample plots were randomly taken in each plot to measure the coverage of *A. fruticosa* and the total coverage of all species, three times a month. Invaded native species were recorded. The same measurement was also made from April to August 2014. In this study, a coverage of 60% was assumed to be fair, and a coverage of 80% was assumed to be good, because erosion risk was low in slopes under 30°with a fractional vegetation cover of 60~80% based on an erosion model (Vrieling *et al.*, 2006). The duration of total coverage higher than 60% and 80% were calculated respectively by the following equation:

$$\text{Duration of fair or good coverage} = \frac{\text{the number of days when total coverage} \geq 60 \text{ or } 80\%}{\text{the number of days for coverage measurement}} \times 120 \quad \text{d}$$

Coefficient of variation (CV) of total coverage during the experimental period was calculated to describe the stability of total vegetation coverage. Each CV value of different $R_{s/h}$ taken as a sample, Friedman test for non-parametric paired samples was used to test the significance of variation between the CV values of different combinations of shrub and herbaceous species.

In the end of October 2013, 15 individuals of *A. fruticosa* in each plot were randomly taken to measure height and ground diameter. ANOVA was used to test the effect of herbaceous species and $R_{s/h}$ on the growth of *A. fruticosa* where T0 was used as control. Normality of samples was tested before significance test, and when the effect was significant ($P < 0.05$), LSD was used to test comparisons among different seed mixture designs. Statistic analysis was performed using SPSS program.

3 Results

3.1 The effect of species on total coverage

As shown in Figure 2, from July to October 2013, T4 had the highest total coverage, regardless of the the ratio of shrub to herbaceous seeds ($R_{s/h}$). The performance of other seed mixtures differed with time. In July, when $R_{s/h}$ were 1:9, 3:7, 4:6 and 5:5, T2 had the second highest total coverage, and when $R_{s/h}$ were 2:8, 6:4, 8:2 and 9:1, T3 had the second highest total coverage. T1 had the lowest total coverage in July. From August to October, when $R_{s/h}$ were 1:9~3:7, T2 had a higher total coverage than T1, and when $R_{s/h}$ were 6:4~9:1, T1 had a higher total coverage value than T2. T3 had a relatively low total coverage from August to October, which was also shown in T2t8 and T2t9.

3.2 The effect of $R_{s/h}$ on total coverage

As shown in Figure 3, $R_{s/h}$ had different effects on the dynamics of total coverage in different species combination.

T0: A. fruticosa took longer time to form a fair coverage and maintained a fair or good coverage for much shorter period compared to herbaceous species. Total coverage of T0 was lower than 60% in July and October, but higher than 80% in August and September.

T1: In July, 6 out of 10 plots including t2, t5~t9 had a total coverage higher than 60%, among which t7 had a total coverage higher than 80%. In August, except for t0 and t1, all plots had a total coverage higher than 80%. Since September, all plots had a total coverage higher than 80%.

T2: In July, 7 out of 9 plots including t1, t3~t8 had a total coverage higher than 60%, among which t3 and t5 had a total coverage higher than 80%. In August, except for t9, all plots had a total coverage higher than 80%. Since September, t1~t7 had a total coverage higher than 80%. The total coverage of t8 and t9 was good in September, but both fell to 77% in October.

T3: In July, 9 out of 10 plots including t0, t2~t9 had a total coverage higher than 60%, among which t6 had a total coverage higher than 80%. In August, all plots had a total coverage higher than 60%, among which t0, t6~t9 had a total coverage higher than 80%. The total coverage of most plots was maintained till October except for t2, which enhanced total coverage since September, t1 and t3~t5, which enhanced total coverage in October, and t9, which decreased total coverage to a value lower than 60% in October.

T4: Since July, all plots achieved a total coverage higher than 80%.

3.3 Duration and stability of total coverage

From July to October (counted as 120 d), duration of fair coverage was 76, 107, 112, 112, and 120 d (mean values of different $R_{s/h}$, the same below) from T0 to T4, respectively. Duration of good coverage was 65, 84, 95, 82 and 109 d from T0 to T4, respectively. In this respect, T4 had the best performance, followed by T2, T3, T1 and T0. T1 and T3 had relatively poor performance compared to T4 and T2, but T1t5, T1t7, T3t7 and T3t8 maintained a good coverage more than 100 d. Even though T2 had the second best performance in general, T2t2 and T2t9 maintained a shorter period of fair or good coverage compared to T1 or T3 of the same $R_{s/h}$. Remarkably, when $R_{s/h}$ was 6:4 and 7:3, all combinations of shrub and herbaceous seeds maintained a fair coverage for 120 d, i.e. the whole experimental period. As a result, this ratio of shrub to herbaceous seeds is proposed for seed mixtures applied in rapid revegetation.

T0 not only had the shortest duration of fair or good coverage, but also had the highest coefficient of variation (46%), indicating its least stability among all plots. The coefficient of variation from T1 to T4 were 19, 15, 19 and 9%, respectively. The coefficient of variation of T4 was significantly lower than those of T1, T2 and T3 ($P<0.05$). In T1, plots with a $R_{s/h}$ of 5:5~9:1 had relatively low coefficient of variation, ranging from 10 to 16%. In T2, plots with a $R_{s/h}$ of 1:9 and 3:7~8:2 had relatively low coefficient of variation, ranging from 10 to 15%. In T3, plots with a $R_{s/h}$ of 2:8, 3:7, 6:4~8:2 had relatively low coefficient of variation, ranging from 11 to 15%.

3.4 The effect of herbaceous species on the coverage of *A. fruticosa*

The average coverage of T0 during the experiment period was 74.6%. Assuming the coverage was proportional to the amount of seeds we sowed, some seed mixtures had a positive effect on the coverage of *A. fruticosa*, including T1t1~T1t7, T3t8~T3t9 and T4t7~T4t9, while other seed mixtures had a negative effect on the coverage of *A. fruticosa*, as shown in Figure 4.

When *A. fruticosa* was sowed alone, fair coverage was achieved on 30th July. When herbaceous species were sowed with *A. fruticosa* with a $R_{s/h}$ ranged from 1:9 to 3:7, the coverage of *A. fruticosa* was lower than 60% during the whole experimental period in any combination of seed mixtures. When the $R_{s/h}$ ranged from 4:6 to 7:3, the coverage of *A. fruticosa* in T1 reached 60% first, on 30th Aug, 20th Jul, 30th Jul and 10th Aug, respectively. When the $R_{s/h}$ ranged from 8:2 to 9:1, the coverage of *A. fruticosa* in T4 reached 60% first, both on 20th Jul. In plots of T1t9, T2t7~T2t9, T3t6~T3t9, T4t6~T4t7, *A. fruticosa* also achieved a coverage of 60%, but in later period of the rainy season.

3.5 The effect of $R_{s/h}$ and herbaceous species on the growth of *A. fruticosa*

There was a negative effect of herbaceous species on the growth of *A. fruticosa*, as shown in Table 4. In T1, height growth of *A. fruticosa* was significantly lowered when $R_{s/h}$ were 1:9~3:7 and 6:4~8:2, while ground diameter was significantly lowered when $R_{s/h}$ were 1:9, 2:8 and 7:3, compared to T0. In T2, height and diameter growth of *A. fruticosa* were significantly decreased in all $R_{s/h}$ compared to T0. In T3, height growth of *A. fruticosa* was significantly lower than T0 in all $R_{s/h}$, while ground diameter was significantly lower than T0 when $R_{s/h}$ were 2:8~6:4 and 9:1. In T4, height growth of *A. fruticosa* was significantly lowered when $R_{s/h}$ were 3:7~5:5 and 7:3, while ground diameter was significantly lowered when $R_{s/h}$ was 4:6, compared to T0.

When different combinations of species with the same $R_{s/h}$ were compared (T1~T4), the values of height and ground diameter were the highest in T3 when the $R_{s/h}$ were 1:9 and 2:8. When the $R_{s/h}$ were 3:7~5:5, T1 had highest value of height and generally the highest value of ground diameter. When the $R_{s/h}$ were 6:4~9:1, T4 had the highest values of height and ground diameter.

3.6 Dynamics of the established plant communities in the subsequent year

T1 was damaged in 2014 so the data are not reported. As to other plots, in April 2014, T2t1~T2t5, T3t0~T3t8, and T4t0~T4t5 had a total coverage higher than 80%, and T3t9 had a total coverage higher than 60%. In May, except for T2t6, T3t2~T3t5, all plots had a total coverage higher than 80%. In June, the total coverage of T2t1, T2t5 and T3t0~T3t5 decreased and was lower than 60% because of the wilting of *O. Violaceus* since April.

Since May, T0 and all plots of T4 achieved a total coverage higher than 80%. Since July, all plots of T2 achieved a total coverage higher than 80%. In August, T3t0~T3t1 had a total coverage ranging from 70 to 73%, while the other plots of T3 achieved a total coverage higher than 80%.

4 Discussion

4.1 The effect of species selection and $R_{s/h}$ on total coverage

Vegetation cover is one of the main factor controlling the effect of soil protection from wind and water erosion (Ferreira & Panagopoulos, 2014). An early recovery of vegetation cover can prevent water erosion during the rainy season, while the stubble and litters can prevent wind erosion during the following dry season. Two months after sowing, total coverage of T0, T1t0, T1t1, T1t3, T1t4, T2t2, T2t9 and T3t1 were lower than 60%, so they are not proposed for rapid revegetation.

Based on the speed and the stability of coverage, sowing seed mixtures performed better than sowing shrubs alone, which was consistent with Gilardelli *et al.* (2014). Among the combinations of shrub and herbaceous species, T4 showed its excellency in fast ground cover formation and high coverage maintenance around the whole experimental period, most attributed to *V. philippica*. According to our results, sowing *V. philippica* with a seeding rate of 1.5 $g \cdot m^{-2}$ is efficient in rapid revegetation in northern China or regions where the climate and soils are similar. A higher seeding rate may be a waste of seeds and more seriously, the dense ground cover may hinder the recolonization of other native species. In plots where *O. violaceus* instead of *V. philippica* was sowed with *A. fruticosa*, a coexistence with local annual or perennial herbs such as *Bidens pilosa* L., *Acalypha australis* L., *Amaranthus retroflexus* L., *Euphorbia humifusa* Willd., *Abutilon theophrasti* Medic., *Artemisia annua* L., *Convolvulus arvensis* L. and *Polygonum lapathifolium* L. was observed, but not in T4.

Other than T4, T2 had a fast cover formation when $R_{s/h}$ was low, and T3 had a fast cover formation when $R_{s/h}$ was high. Sowing *F. arundinacea* alone was not appropriate for rapid revegetation because it covered the ground slowly. But considering the whole experimental period, T1 had a relatively high total coverage when $R_{s/h}$ was high. As a result, *F. arundinacea* should be mixed with other fast-growing species and a seeding rate of 1.5~6.0 $g \cdot m^{-2}$ is proposed in order to achieve high value of total coverage. T3, i.e. *O. violaceus* covered soil rapidly, but had the lowest total coverage considering the whole experimental period. Because *O. violaceus* wilted when the seeds were ripe, a significant decline of *O. violaceus* was observed, though total coverage was hardly affected thanks to the development of *A. fruticosa*.

Before the experiment, we supposed that the stability of total coverage was correlated with the tolerance to environmental stress. For example, because of the stochastic nature of precipitation, wilting, defoliation or die off during water deficiency may weaken the protective effect of vegetation when rain storm finally occurs (Zuazo & Pleguezuelo, 2008). Compared to herbs, woody species were supposed to maintain a more stable coverage because they could use the resource in the deep soil layers or at least they have longer life (Wang *et al.*, 2005). Contrary to expectation, results showed that T0 had the highest coefficient of variation among all plots. If *A. fruticosa* could use the water stored in the deep layers, its coverage would not fluctuate in spite of the temporal water deficiency (the longest interval between rainfall events was 17 days during our experiment), and thus the coefficient of variation would be small. The high value of coefficient of variation in T0 indicated that the ability to conserve water and the resistance against environmental stress was not fully developed in *A. fruticosa*.

Some plots including T2t2, T2t9 and T3t1 had a low total coverage, and no pattern was observed between these plots and the adjacent plots. It was supposed that random factors such as the variation of seeds and microsite conditions accounted for the poor performance of these plots. However, natural ecosystems are much more diverse than our study plots. Microsites are spatially heterogeneous, weather events are stochastic by nature, and the inter- or intraspecific relationship may vary in different stages of individual development and community succession (Zanini *et al.*, 2006). To deal with the spatial and temporal heterogeneity, more species should be used in artificial revegetation because of their adaptation to different niches and thus the reconstruction of the whole plant community is more likely to succeed even if some species fail (Sheley &Half, 2006).

4.2 The effect of herbaceous species on the growth of shrub

The coverage of *A. fruticosa* in T1t5, T4t8 and T4t9 reached 60% 10 days earlier than T0, even though fewer seeds were sowed in these plots, indicating a positive effect of herbaceous species on the coverage of *A. fruticosa*. Compared to T0, the average coverage of *A. fruticosa* during the study were higher in T1t1~T1t7, T3t8~T3t9 and T4t7~T4t9, but average height and ground diameter were lower in these plots, indicating that the individuals were smaller, but the number of individuals was higher when herbaceous species were sowed together. The result was in consistent with the research by Mason *et al.*(2013), which showed that ground cover was favorable for shrub germination but disadvantageous to growth. Moreover, when a field study was made in May 2014, it was observed that the sprout number of each individual of *A. fruticosa* ranged from 3 to 5 in T0, but more than 6 in T1t9 and T4t9, which may partly account for the inconsistency between high coverage and low growth in these plots.

Competition for resources, such as water, may explain the decline of growth of *A. fruticosa*. Soil water content is determined by the input such as precipitation and irrigation together with the output such as infiltration and evapotranspiration. Plants can increase infiltration rate (Ji *et al.*, 2008) and water holding capacity but also consume a large amount of water during transpiration. As a result, soil water content may be increased or decreased by coexisting species (Bréda *et al.*, 1995, D'Odorico *et al.*, 2007). Competition may also exist for nutrition or light, but the relationship differs among different species (Denslow *et al.*, 2006; Mendoza-Hernández *et al.*, 2014). Researches indicated a very comprehensive relationship between different coexisting species, not only negative but also positive relationship were shown in different studies (Harmer *et al.*, 2011, Ballesteros *et al.* 2012; Zhang *et al.*, 2013; Oliveira *et al.*, 2014).

Other than interspecific competition, intraspecific competition exists. Competition for light between individuals of *A. fruticosa* was more intense in T0 than other plots, especially when $R_{s/h}$ was low. In T0, short and weak individuals may be weeded out and only the tall and strong ones which have access to light survive, leading to a higher mean value of growth. Compared to height, ground diameter was less correlated to the competition for light, so it was also less corrected to $R_{s/h}$. However, this hypothesis needs to be tested.

5 Conclusions

Firstly, shrub cover was formed slower than ground cover, and was maintained for a shorter period at least in the early stage of development. When herbaceous species were sowed with shrubs, total coverage increased and was maintained for a longer period, but the growth of shrubs was hindered. Secondly, in the practice of rapid revegetation in North China Plain or wherever the soil and climate are similar, the ratio of shrub to herbaceous seeds is proposed to be 6:4~7:3 by mass. Thirdly, herbaceous species have different traits. In our experiment, three different types of herbaceous were found, i.e. slow-growing stable species (*F. arundinacea*), fast-growing unstable species (*O. violaceus*), and fast-growing stable species (*V. philippica*). Slow-growing stable species and fast-growing unstable species should not be used alone because they cannot cover the ground fast or they cannot maintain a long period of coverage. A small seeding rate of fast-growing stable species should be used to ensure a fair coverage against erosion, and other species with different traits should be added to enhance the stability of plant community. Fourthly, in the practice of rapid revegetation in North China Plain or wherever the soil and climate are similar, seeding density of *F. arundinacea* is proposed to be lower than 6 g • m^{-2} and the seeding density of *V. philippica* is proposed to be 1.5 g • m^{-2}.

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Tables

Table 1 Chemical properties of the local soil

Organic matter ($g \cdot kg^{-1}$)	Total N ($g \cdot kg^{-1}$)	Available N ($mg \cdot kg^{-1}$)	Available K ($mg \cdot kg^{-1}$)	Available P ($mg \cdot kg^{-1}$)
4.72	2.47	19.06	22.23	4.74

Table 2 Characters of target species

Species	Family	Life form	Average size
Amorpha fruticosa L.	Leguminosae	Deciduous shrub, Fl. May-Jun, fr. Jul-Sep.	1~4 m
Festuca arundinacea Schreb.	Gramineae	Cool-season perennial C_3 species of bunchgrass, Fl. and fr. Jun-Sep.	30~100 cm
Orychophragmus violaceus O. E. Schulz.	Cruciferae	Herbs annual or biennial, Fl. Mar-Jun, fr. May-Jul.	15~60 cm
Viola philippica Car.	Violaceae	Herbs perennial, Fl. Apr-May, fr. May-Sep.	4~14 cm

Table 3 Designs of seed mixture

No.	Species	Ratio by mass
T1	*A. fruticosa*: *F. arundinacea*	0:10, 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, 9:1
T2	*A. fruticosa*:*O. violaceus*:*V. philippica*	The ratio of shrub to herbs was the same with T1, and the masses of *O. violaceus* and *V. philippica* were the same.
T3	*A. fruticosa*:*O. violaceus*	The design of T3 was the same with T1.
T4	*A. fruticosa*:*V. philippica*	The design of T4 was the same with T1.
T0	*A. fruticosa*	

Note: the thousand grain weight of *A. fruticosa*, *F. arundinacea*, *O. violaceus*, and *V. philippica* are 6.163, 2.814, 2.175 and 0.981 g respectively.

Each plot is denoted as Txty. The capital letter T indicates species, and the following x ranges from 0 to 4, indicating different combinations of species. The small letter t indicates the proportion of shrub seeds, and the following y ranges from 0 to 9, indicating the percentage of *A. fruticosa* in the seed mixture by mass, which equals to y/10.

Data of T2t0 are deleted because of deficient setting of the experimental plot.

Table 4 Average height and ground diameter of *A. Fruticosa*

	Height (cm)				Ground diameter (cm)			
	T1	T2	T3	T4	T1	T2	T3	T4
t1	34^{*}	30^{*}	35^{*}	-	0.423^{*}	0.431^{*}	0.668	-
t2	31^{*}_{A}	44^{*}_{B}	45^{*}_{AB}	-	0.328^{*}_{A}	0.672^{*}_{B}	0.679^{*}_{B}	-
t3	52^{*}_{A}	33^{*}_{B}	39^{*}_{B}	49^{*}_{A}	0.639_{AB}	0.563^{*}_{A}	0.594^{*}_{AB}	0.781_{B}
t4	65_{A}	35^{*}_{B}	43^{*}_{B}	50^{*}_{AB}	0.807	0.594^{*}	0.626^{*}	0.737^{*}
t5	73_{A}	36^{*}_{C}	49^{*}_{BC}	61^{*}_{AB}	0.795_{A}	0.515^{*}_{B}	0.705^{*}_{AB}	0.834_{A}
t6	63^{*}_{AB}	50^{*}_{A}	55^{*}_{A}	82_{B}	0.679_{A}	0.652^{*}_{A}	0.756^{*}_{AB}	1.063_{B}
t7	53^{*}_{A}	56^{*}_{A}	66^{*}_{AB}	73^{*}_{B}	0.593^{*}_{A}	0.669^{*}_{A}	0.853_{B}	0.889_{B}
t8	55^{*}_{A}	63^{*}_{AB}	70^{*}_{B}	89_{C}	0.715	0.687^{*}	0.837	0.899
t9	79_{AC}	54^{*}_{B}	73^{*}_{A}	93_{C}	0.849_{A}	0.571^{*}_{B}	0.761^{*}_{A}	0.858_{A}
T0	92				0.926			

Note: the superscript * indicates a significant difference compared to T0 ($P < 0.05$). The subscript of the same letter or the absence of subscript indicates that the mean values of height or ground diameter in the same row were not significantly different.

No *A. fruticosa* survived in T4t1 and T4t2, and only 5 and 2 individuals of *A. fruticosa* survived in T2t1 and T3t1 respectively.

Figures

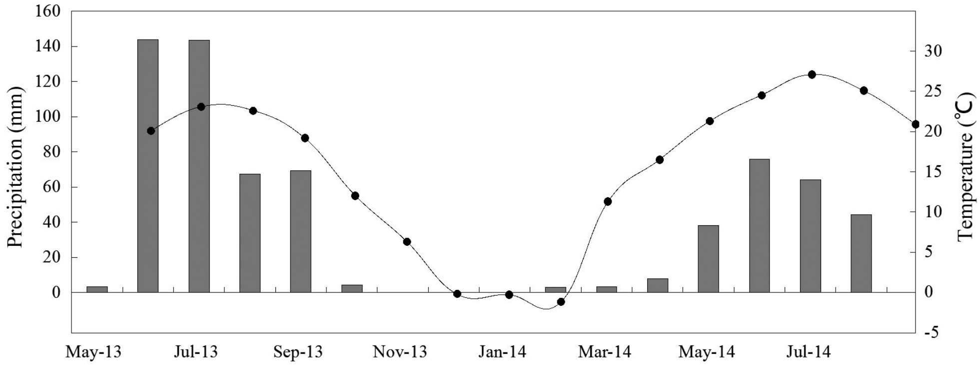

Fig. 1. Monthly precipitation and average temperature

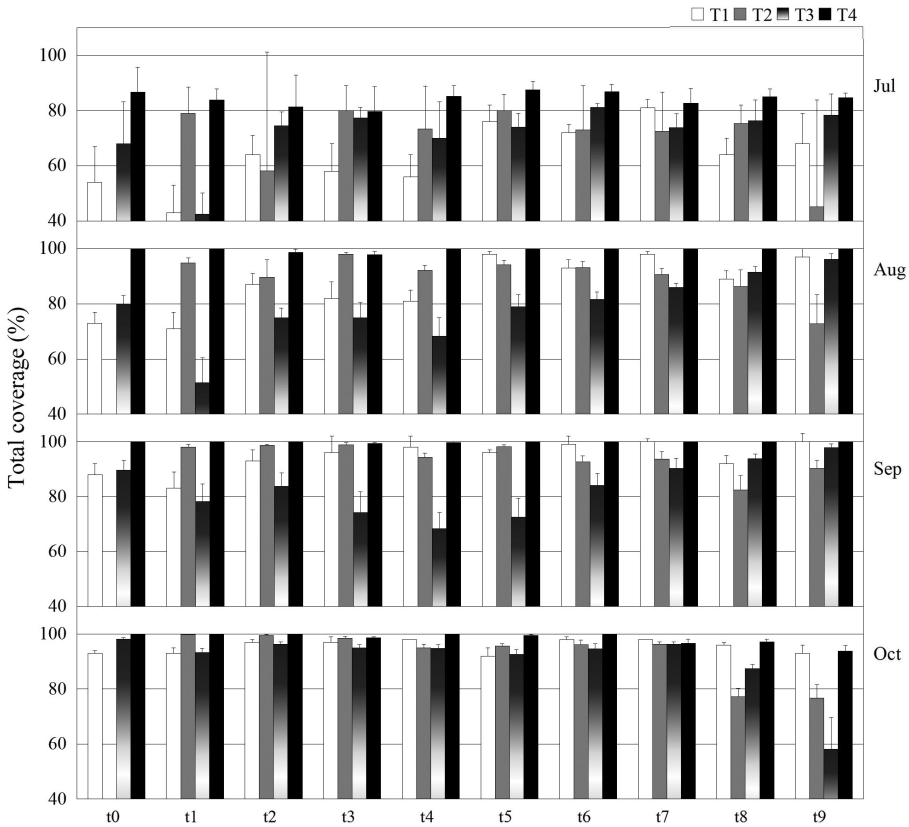

Fig. 2. Total coverage of different combinations of shrub and herbaceous seeds (±SE)

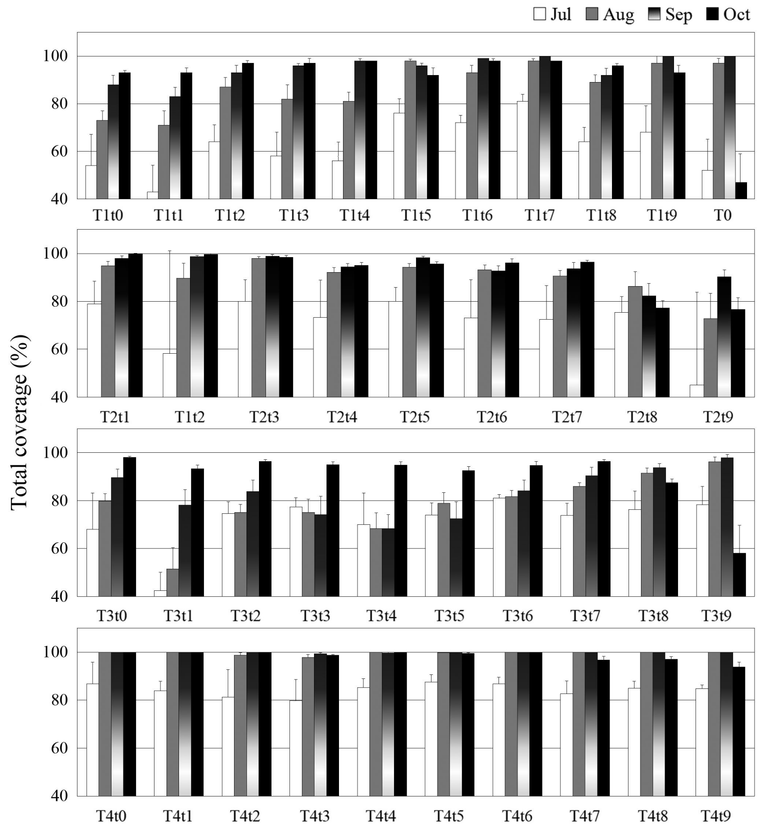

Fig. 3. Dynamics of total coverage (±SE)

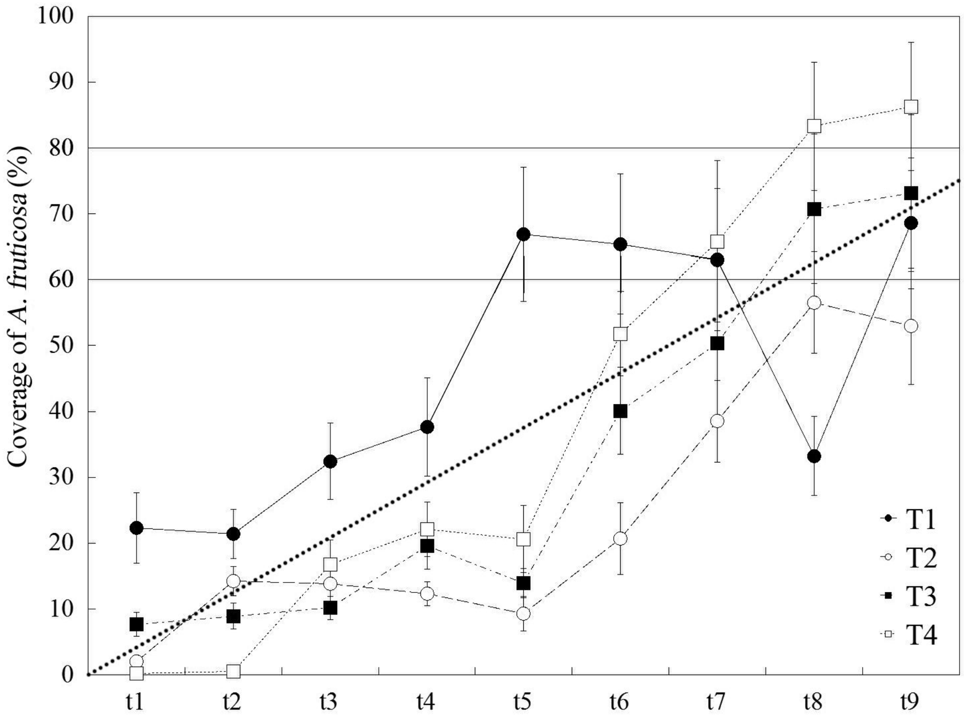

Fig. 4. Coverage of *A. fruticosa* sowed with different herbaceous seeds

Note: each spot with error bar is the mean value of coverage of *A. fruticosa* during the experimental period. The dotted line indicates a predicted coverage of *A. fruticosa* under different seeding density, based on the assumption that the coverage is proportional to the amount of seeds sowed.