Effects of Agriophyllum squarrosum seed banks on its colonization in a moving sand dune in Hunshandake Sand Land of China

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Received 27 September 2002; received in revised form 11 August 2003; accepted 14 January 2004

Abstract

A field study was conducted in a moving sand dune to detect the effects of different positions of the dune and the burial depth on seed number, germination rates of Agriophyllum squarrosum in the soil seed banks and its colonization during natural succession processes. The results showed that wind and the movement of sand played an important role in the colonization of A. squarrosum seed banks. The positions of sand dune and burial depth significantly affected the number of seeds in soil seed banks. The number of seeds was more abundant at the top of the dune and windward slope than at leeward slope, and it reached a maximum at the 10–20 cm depth. The number of seeds was fewer at leeward, and decreased with increasing burial depth. However, there was no significant difference in the germination rates of seeds among positions of the sand dune. Therefore, the plant density at the windward slope and tops was higher than that at leeward. Our results suggested that the seeds of A. squarrosum were more likely to be deposited at the dune tops and windward slopes than at leeward, and thus to form larger seed banks. At the sand dune tops and the windward slope, the seed number at 10–20 cm depth was much greater than at 0–5 and 5–10 cm burial depths. However, the germination rate of seeds at 0–5 and 5–10 cm depths were significantly higher than that at 10–20 cm depth. The results indicated that it was the germination rate at the top 0–5 and 5–10 cm, rather than the total number at the 10–20 cm that determined the observed higher density of A. squarrosum at the dune tops and the windward.

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Keywords: Agriophyllum squarrosum; Seed banks; Moving sand dune; Germination rates; Plant density

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1. Introduction

Soil seed banks play prominent ecological and evolutionary roles in linking the past, present, and future plant population and community structure and dynamics in a given habitat (Thompson and Grime, 1979; Leck et al., 1989). They are especially important in desert ecosystems where annual plants account for a large part of the flora and their seeds may remain viable in the soil for many years (Kemp, 1989, pp. 257–282; Inouye, 1991, pp. 27–54; Guo et al., 1999). Viable seeds buried in the soil are part of the plant community and a source of new individuals (Simpson et al., 1989, pp. 3–8; Mayor et al., 2003), and also an important basis for recruitment and regeneration of vegetation (Yang and Zhu, 1995).

Agriophyllum squarrosum is an annual herb in the Hunshandake Sand Land, and belongs to Agriophyllum M.Bieb. of Chenopodiaceae. This species is often found on naked sandy patches of moving and semi-fixed sand dunes in the arid and semi-arid areas. In the moving and semi-moving sand dunes, the colonization of A. squarrosum community plays an important role in stabilizing mobile sand dunes. This could simultaneously facilitate conditions for the establishment of colonizing species, which in turn could change the trajectories of community succession (Vitousek and Walker, 1989). The colonization of A. squarrosum community could be an indicator of the restorative succession. Therefore, quantifying the seed banks of A. squarrosum are of great importance for studying restorative succession processes of plant community in the desert ecosystems. Although several studies were conducted on the biological characteristics and seed morphology of A. squarrosum (Li et al., 1992; Chang et al., 2000), relationships between the spatial distribution of seeds and the observed patterns of the plant community have not been given enough attention.

We conducted an experiment to examine the number of seeds in the soil seed banks, their germination rates and the colonization of A. squarrosum community, a pioneering community conducive to sand stabilization. The aims of this study were to: (1) determine the relationships between seed number in soil seed banks, seed germination rates and plant density in a moving sand dune, (2) analyse the successional processes of moving sand dunes as related to the spatial distribution of A. squarrosum seed banks and germination rates, and (3) gain knowledge as to how to restore the degenerated moving and semi-fixed sand dunes.

2. Materials and methods

2.1. Study site

The experiment was carried out in Duolun county of Xilingol League, Inner Mongolia (41°46′–42°36′N; 115°51′–116°54′E), situated across the southern edge of Hunshandake Sand Land. With a gentle relief, flat lands or interdunal depressions were formed surrounded by sand dune ridges.

Temperate semi-arid continental monsoon climate characterizes the region, in which the windy and dry weather usually prevails in the spring and winter, with a
wind speed of averaging 4–5 m s\(^{-1}\). The annual mean precipitation is about 385.5 mm and the mean potential evaporation is almost 1748 mm. The annual mean temperature is 1.6°C, the accumulated temperature of \(\geq 10^\circ C\) is 1917.5°C, and the frost-free period is 100 days. The monthly average precipitation and wind speed in the study area in 2001 were given in Fig. 1. Main precipitation period is from June to October in this area.

The dominant plant species distributed on fixed and semi-fixed sand dunes were *Salix gordejevii*, *Hedysarum leave*, *Psammochloa villosa*, *Pennisetum centrasiaticum*, *Melissitus ruthenicus*, *A. squarrosum* and a few others, but *A. squarrosum* is basically the single dominant species found on the moving sand dunes.

2.2. Experimental methods

The 4 ha experimental plot in the area was selected on a moving sand dune, which had been fenced for 1 year prior to the commencement of the experiment.

We used the line transect method to sample the seed bank on May 16, 2001, at leeward, the top and windward slope of the sand dune, respectively. Each 100-m line transect perpendicular to the main wind direction in three different positions on a moving sand dune was chosen, and a set of soil samples were taken every 10 m along the transect. Soil samples were taken in a rectangular plot of 25 cm \(\times\) 25 cm with a shovel, and separated into 4 layers (0–5 cm, 5–10 cm, 10–20 cm and 20–30 cm, respectively). Soil samples were brought to the laboratory, and then carefully washed with clean water. The number of seeds in every soil sample was recorded. The seeds from the same soil layer were mixed, divided into three parts, and then used for conventional germination experiment using a growth chamber with a constant temperature of 25°C.

The measurement of plant density was similar to that for the seed banks. Plant density was measured every 20-m on the transect at various positions of the sand dunes. The sampling plot was 1 m \(\times\) 1 m by size, and 5 samples were taken within every 20-m transect. The number of seedlings in each sampling plot was enumerated on June 19, 2001 and the density of mature plants was measured on August 3, 2001.
2.3. Data analysis

To compare the number of seeds and germination rates among different positions and various burial depths, a Two-Way ANOVA was performed to test the significant difference between 3 positions of the dune as a function of burial depth. For the plant density, a One-Way ANOVA was used to test the significant differences of sampling positions in the sand dune. Means were separated using Duncan’s Multiple-Range Test.

3. Results

3.1. Seed banks of *A. squarrosum*

The number of seeds in the seed banks decreased with increasing burial depth at leeward of the sand dune, and there were fewer seeds at the 20–30 cm depth. However, number of seeds at windward slope and tops was larger than that at leeward, and it reached a maximum at 10–20 cm depth with densities of 358 granule m^{-2} (tops) and 843 granule m^{-2} (windward slope) respectively.

The position of sand dune and burial depth significantly affected the number of seeds in soil seed banks \( p < 0.05 \). Results of Duncan’s Multiple-Range Test for various positions showed that there were significant differences in the number of seeds between the leeward and windward slope, tops at all burial depths. However, there was no significant difference between 0–5 cm and 5–10 cm depth at windward slope and tops respectively \( p > 0.05 \), while significant difference was found between 10–20 cm and 20–30 cm depth \( p < 0.05 \). With respect to the burial depths, number of seeds was largest at 0–5 cm of leeward, and significant difference was detected between 0–5 cm and other burial depth \( p < 0.05 \). Number of seeds at 10–20 cm deep was largest at the windward and tops, and there were significant differences between 10–20 cm depth and other burial depths (Table 1).

3.2. Germination rates

Germination rates of seeds in soil seed banks were not related to positions of sand dune, but the burial depth significantly affected the germination rates of seeds

<table>
<thead>
<tr>
<th>Various positions</th>
<th>Burial depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–5</td>
</tr>
<tr>
<td>Leeward</td>
<td>81.6 ± 19.2c</td>
</tr>
<tr>
<td>Tops of dune</td>
<td>153.6 ± 33.9a</td>
</tr>
<tr>
<td>Windward slope</td>
<td>152.0 ± 46.5a</td>
</tr>
</tbody>
</table>

Note: Data of the table represent mean ± standard error. Pairs sharing the same letter are not significantly different at \( p < 0.05 \).
(p < 0.05), and it decreased with increasing burial depth at the three positions of the sand dune. At the three positions, the highest germination rates (12.5–15.2%) were found in the surface layer (0–5 cm). As indicated by the statistics of Duncan’s Multiple-Range Test, at leeward and tops, there were significant differences in germination rates among the upper two layers (5 cm, 5–10 cm deep) and the lower two layers (10–20 cm, 20–30 cm deep) (p < 0.05) and among burial depth of the sand dune at the windward (Table 2).

3.3. Plant density

Among all the positions of the sand dune, the densities of sprouting seedlings and mature plants were highest at the tops and lowest at the leeward. The statistics of Duncan’s Multiple-Range Test for the densities of sprouting seedlings showed that there were significant differences between the leeward and tops, windward slope (p < 0.05), but no significant difference between the tops and windward slope (Fig. 2). The results for mature plant densities were same as for seeding densities.

Table 2
Seed germination rates at various burial depth and the result of Duncan multiple range test

<table>
<thead>
<tr>
<th>Burial depth (cm)</th>
<th>Various positions</th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leeward</td>
<td>Tops</td>
<td>Windward slope</td>
<td></td>
</tr>
<tr>
<td>0–5</td>
<td>12.5 ± 4.2a</td>
<td>15.2 ± 1.7a</td>
<td>14.4 ± 1.6a</td>
<td></td>
</tr>
<tr>
<td>5–10</td>
<td>11.2 ± 2.9a</td>
<td>11.3 ± 4.8a</td>
<td>9.4 ± 0.9b</td>
<td></td>
</tr>
<tr>
<td>10–20</td>
<td>6.3 ± 0.5b</td>
<td>6.3 ± 0.4b</td>
<td>8.4 ± 4.1bc</td>
<td></td>
</tr>
<tr>
<td>20–30</td>
<td>— a</td>
<td>4.6 ± 0.3b</td>
<td>4.0 ± 2.0c</td>
<td></td>
</tr>
</tbody>
</table>

Note: Treatments with different letters in one list are significantly different at p < 0.05 level.

*a* No Duncan multiple-range test because there is no seed at 20–30 cm burial depth.

![Fig. 2. Plant densities of sprouting seedling and mature plant at various positions of dune.](image-url)
4. Discussion

The soil seed banks play a very important role in the succession processes of vegetation and seed dispersal. Many studies have been carried out on soil seed banks in different vegetation types (Roberts, 1981; Peco et al., 1998). Despite these researches focused on the spatial and temporal distribution and restorative succession in the arid and semi-arid area (Henderson et al., 1988; Coffin and Lauenroth, 1989; Yang and Zhu, 1995), the studies on the seed banks of *A. squarrosum* as a pioneering species in moving sand dunes have not been reported.

The seeds of most desert plants have their unique dispersal and germination mechanisms (Gutterman, 1994). Li et al. (1992) studied germination characteristics of *A. squarrosum* and reported that germination time takes about a week in the field, but few seeds could germinate within 1–2 days after seeding. This character is a very adaptive mechanism to quick germination when rainfall occurs. And germination rate was 17.0% under artificially manipulated conditions buried sand with 3 cm depth in the field in a moving sand dune. This experimental result was similar to our present study. The germination rate of *A. squarrosum* is much lower either in the laboratory or in the field, but this germination characteristics has implications for species conservation.

Wind has an important effect on the movement and deposition of sand, which in turn affects the colonization of *A. squarrosum* community. The position of sand dune and burial depth significantly affected the number of seeds in soil seed banks. Number of seeds at windward slope and tops was larger than that at leeward, but there was no significant difference in the germination rates of seeds between every position of sand dune. Therefore, the plant densities at windward slope and tops were higher than that at leeward. Our results suggested seeds of *A. squarrosum* were more likely to be deposited at the dune tops and windward slopes than at leeward, and thus to form larger seed banks. As a result, *A. squarrosum* would be more easily to develop at the dune tops and windward slopes. Germination rates at 10–20 cm and 20–30 cm depths were lower than that at 0–5 cm and 5–10 cm burial depths. We concluded that the role of seed banks at 0–10 cm depth for colonization was larger than those other depths.

The mechanism and the direction of community succession have attracted intensive attention of ecologists (Gorham et al., 1979). *A. squarrosum* is a pioneering species in moving sand dunes, and it mainly occurs in the early stage during succession in psammophytic vegetation. Based on the hypothesis of multiple succession pathways, it is concluded that succession depends greatly on environmental factors. Liu (1985) ever studied the natural sand fixation process in Zhanggutai of Liaoning Province, and found that the succession process included several stages from moving to fixed sand dunes: (1) invasion and colonization of *A. squarrosum*, a pioneer species; (2) invasion and establishment of *Artemisia halondendrom*; (3) subsequent establishment of the climax community dominated by climax species, such as *Leymus chinensis* and *Agropyron cristatum*. Whether the succession of Hunshandake Sand Land would go through the same pathways as
above is still unknown. Further researches need to be done to extend knowledge of the restorative succession in the Hunshandake Sand Land.

Acknowledgements

The authors are very grateful to Pr. Han Xingguo and Dr. Wang Zhenwen for the revision of the manuscript. This research project is supported in part by the Major Project of the Chinese Academy of Sciences (KSCX1-08) and by the National Key Basic Research Special Foundation Project (NKBRSF Project G2000018607).

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