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RESEARCH ARTICLE

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Effects of solid water and foliar fertilizer on survival and growth of seedlings in sand prevention and control

Abstract To promote afforestation in sandy lands and increase the effects of prevention and control of desertification, the application of a new drought-resistant product—solid water and foliar fertilizer "Shifengle"—was studied. A comparison of three treatments (solid water, foliar fertilizer, and control) showed that both solid water and foliar fertilizer increased plant survival rate by 10% and 18.2%, respectively. Afforestation survival rates of *Salix psammophila* and *Hedysarum mongolicum* reached over 90%. In addition, height and crown growth as well as biomass of seedlings were improved by the treatments.

Keywords solid water, foliar fertilizer, afforestation survival rate, biomass

1 Introduction

In arid and semi-arid regions, strong wind, movable sand and water deficiency are the limiting factors for vegetation restoration and eco-environment improvement. Hence, on top of the selection of species that are resistant to wind erosion and establish sand barriers in sandy land afforestation projects, many antidrought afforestation techniques are widely adopted, such as site preparation, deep planting of trees, covering techniques, water absorbents, water-saving afforestation and water-collecting afforestation (Wang et al., 1997; Li and Qiu, 2003). Solid water planting technology is a novel technology for planting initiated in the late 1990s. Solid water is also called dry water or driwater. Water is solidified with new technologies and its physical properties are considerably changed; water becomes still, fixed, frost-free at 0°C and unmeltable at 100°C. Solid water is mainly used for rehabilitation of eco-environments, such as afforestation of barren mountains, combating desertification, as well as for urban greening (Wang et al., 2001; Yang et al., 2002; Zhao et al., 2002, 2004; Zhou and Li, 2002; Zhou et al., 2002; Chang, 2003). Solid water presents a new idea, in that a minimum amount of water supply, that accompanies water absorption, can help plants survive and grow over a long period. The water released from solid water solution is mainly concentrated in the root system of plants, which greatly increases the efficiency of water use, reduces irrigation cost in arid and semi-arid regions and provides suitable approaches for afforestation in severe water-deficient environments (Yang et al., 2001; Zhao et al., 2002; Zhou et al., 2002). The traditional idea that storing and releasing water depend on materials that can absorb and conserve water is not true. Zhou et al. (2002) first studied the effect of solid water on the growth of *Pinus tabulaeformis* and *Platycladus orientalis* seedlings from aspects of water condition, soil moisture content and microbial quantity in the greenhouse. Zhao et al. (2002, 2004) used solid water for afforestation and achieved a survival rate of over 90%.

Foliar fertilizer "Shifengle", as an efficient biological product combining plant growth regulators and various microelements, can effectively regulate plant hormones, increase the capability of water absorption, accelerate cell division, strengthen physiological metabolism and growth and help disease and stress resistance (Chang, 2003; Liu et al., 2003). Application of solid water and soaking roots with foliar fertilizer in afforestation for the prevention and control of desertification is rarely reported. Therefore, in order to study the effects of solid water and foliar fertilizer on afforestation in sandy lands, we carried out an afforestation experiment with solid water and foliar fertilizer in the arid and semi-arid regions of the Changhannao and Kubuqi deserts in northern China.

2 Site description

Changhannao is located at Taigesumu of the Ejin Horo Banner (39°00′05″ N, 109°35′30″ E), at elevations between

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319–1,400 m. At the study site, the climate is dry with little rain, intense sunshine, strong winds and heavy sands. The temperature changes greatly with an average value of 6.2°C. Annual rainfall averages around 250–300 mm and the frost-free period lasts for about 130–140 days per year. The terrain consists mainly of migratory dunes, half-fixed dunes and flat sands; migratory dunes account for about 60% of the area. The main plant species are *Artemisia sphaerocephala*, *Cynanchum hancockiunum* and *Agriophyllum sguarrosum*; in the lower part of the dunes *Salix cheilophila* and *Hippophae rhamnoides* are distributed widely.

The afforestation field of Erdos is located at the Kubuqi desert (40°00′44″–40°20′40″N, 109°00′139″–110°30′194″E). The general terrain is high in the south and west and low in the north and east. The northern margin is covered by Yellow River alluvium and the southern edge is adjacent to the Erdos hilly plateau region. The climate is typically continental with average sunshine above 3,000 h, mean annual temperature of 6.1–7.1°C and mean annual precipitation of 240–360 mm, mainly occurring from July to September. The annual 8-scale gale time amounts to 27 days, with a maximum of 48 days. Blowing sands occur for 58 days. The mean annual frost-free period is 130–140 days. The first frost emerges usually in late September and the last frost ends between May 9 and 14 of the following year. The main plant species are *A. sphaerocephala*, *C. hancockiunum, A. sguarrosum* and *Peganum harmala*.

3 Materials and methods

In the Changhannao experiment field, afforestation of *Salix psammophila* was carried out using cuttings of 2–3-year-old twigs; *S. matsudana* was planted using 3 cm diameter stems; *H. mongolicum* was planted with one-year-old seedlings and *Populus × xiaozhuanica* cv. "Opera" using 4–5-year-old seedlings. Site preparation was adopted by digging holes and plant and row spacing was 2 m × 6 m. The following treatments were applied: (1) solid water treatment of 1 kg/stem; (2) soaking roots with 10 mg/kg foliar fertilizer "Shifengle" for 24 h and (3) control. The cross section area of solid water is 25 cm^2 and the length is 40 cm. The angle between incision of solid water and ground was kept over 45° against the seedling root and then covered with soil. The experimental area was 67 hm^2. Afforestation was completed during April 10–20, 2003.

In the Erdos afforestation field, *S. psammophila, H. mongolicum* and *P.* cv. "Opera" were chosen as materials with digging of holes as site preparation; plant and row spacing was also 2 m × 6 m. Planting techniques adopted were the same as in the Changhannao experimental field, for *S. psammophila*, *H. mongolicum*, *Caragana korchinskii* and *P.* cv. "Opera." *C. korchinskii* was planted with one-year-old seedlings. Two measures, i.e., solid water and control, were taken with a solid water dosage of 1 kg/stem. The experimental area covered 266 hm^2. Afforesting time was from April 10 to 20, 2003.

In September 2003, we surveyed survival rate, growth and biomass of seedlings using a random sampling method. One of every four lines was investigated with a total number of more than 300 stems for each treatment (for *S. matsudana* only 60 stems per treatment). The height growth of *S. psammophia* measured was the net aboveground growth in the current year; biomass was the aboveground dry weight measured from a random sample of more than 30 stems. The data were analyzed with Matlab software.

4 Results and analyses

4.1 Afforestation survival rate

Drought, water shortage, heavy wind and sand are the same climatic conditions in both experimental fields that limit the seedling survival rate. However, because the two experiments are located in different geographic areas, some differences exist in their environmental conditions. Therefore, the requirement of seedlings with regard to humidity varies. Humidity in the Erdos field is comparatively worse than that in the Changhannao experimental field.

4.1.1 Survival rate of seedlings in Changhannao

Solid water has the characteristic of slowly releasing moisture to meet plant moisture requirements to a certain degree during water shortage and therefore guarantees the survival of seedlings (Zhao et al., 2002, 2004; Zhou and Li, 2002; Zhou et al., 2002). In the Changhannao experimental field, the highest survival rate of seedlings treated with solid water was 96.6%, with an average of 73.9%, 13.0% greater than that of control; when treated with foliar fertilizer soaking, the highest was 97.3%, with an average of 79.1% and 18.2% greater than that of control. An analysis of variance showed that the differences in survival rates among the three treatments were insignificant ($p = 0.071 > \alpha = 0.05$), but experimental results indicated that both solid water and foliar fertilizer soaking had positive effects on survival rate. Among these results, the survival rates of *S. psammophila, H. mongolicum, C. korchinskii* and *S. matsudana* with solid water were 37.9%, 6.7%, 6.1% and 1.3% higher, respectively, than that of control and with foliar fertilizer soaking 38.6%, 9.0%, 16.3% and 8.9% higher than that of control. Effects of both solid water and foliar fertilizer on the survival rate of *S. psammophila* were better than that of the other species, which is probably because *S. psammophila* was planted by cuttings and cuttings require better water conditions for rooting, survival and growth and the characteristics of slowly released solid water can meet the demands of *S. psammophila* survival and growth during the early years. Foliar fertilizer is a growth regulator and can increase the water absorption rate of plants and strengthen physiological metabolism; at the same time, plant roots may absorb water through immersion and promote the survival rate of seedlings.

Table 1 Survival of seedlings in Changhannao (unit: %)

Means	*S. psammophila*	*P.* cv. "Opera"	*C. korchinskii*	*H. mongolicum*	Mean
Solid water	96.6	90.3	38.0	70.7	73.9
Foliar fertilizer	97.3	92.6	48.2	78.3	79.1
Control	58.7	83.6	31.9	69.4	60.9

Table 2 Survival of seedlings in Erdos (unit: %)

Means	*S. psammophila*	*P.* cv. 'Opera'	*C. korchinskii*	*H. mongolicum*	Mean
Solid water	95.3	85.7	67.1	91.1	84.8
Control	81.3	79.8	55.8	83.8	75.1

4.1.2 Survival rate of seedlings in the Erdos field

Our study results (Table 2) showed that the highest seedlings survival rate treated with solid water reached 95.3%, with an average of 84.8%, 9.7% higher than that of control. Analysis of variance showed that the survival rate differed significantly among the treatments ($p = 0.013 < \alpha = 0.05$). The survival rate of seedlings treated with solid water can be clearly improved. The survival rates of *S. psammophila, H. mongolicum* and *C. korchinskii* reached 95.3%, 91.1% and 67.1%, respectively, which were 14.0%, 7.3% and 11.3% higher than that of control; however, the survival rate of *P.* cv. "Opera" increased only by 5.9%. Tree species might require more water to survive and 1 kg of solid water might not be enough. We suggest that a higher amount of solid water in a later experiment should be supplied. In the study, the effect of solid water was insignificant in Changhannao, but significant in Erdos, which might be caused by climatic conditions. In our investigation, we found that solid water melted completely in Changhannao, but only partly in Erdos in July, 2003, because the Erdos experimental field was covered with bare sand without weeds and the microorganisms were relatively less active in the soil, which led to slow solid water release and provided moisture for a longer time. Therefore, the dosage of solid water should be decided according to tree species and site conditions.

4.2 Survey of growth conditions

S. psammophila and *H. mongolicum* are indigenous species in the Kubuqi desert. The effects of solid water and foliar fertilizer are reflected by height and crown growth.

The results (Figs. 1 and 2) showed that both solid water and foliar fertilizer could increase the height and crown of *S. psammophila* and *H. mongolicum*. In Changhannao, analysis of variance showed that for *S. psammophila* the treatment effects on height ($p = 0.041 < \alpha = 0.05$) and crown ($p = 0.019 < \alpha = 0.05$) were statistically significant. Multiple comparisons showed that the difference between foliar fertilizer and control is significant in height ($\overline{Y_i} - \overline{Y_j} = 11.60 > LSD = 11.50$) and crown ($\overline{Y_i} - \overline{Y_j} = 14.53 > LSD = 10.40$). The differences between solid water and control and between solid water and foliar fertilizer were not significant. Foliar fertilizer combined with microelements can increase water absorption, strengthen physiological metabolism of seedlings and promote cell division and growth. As a result, foliar fertilizer is more beneficial than solid water in the water supply. However, the functions of solid water and foliar fertilizer in *H. mongolicum* were insignificant, because *H. mongolicum* is drought- and wind erosion–resistant and may grow well below the 2/3 height of sand dunes. In the Erdos afforestation

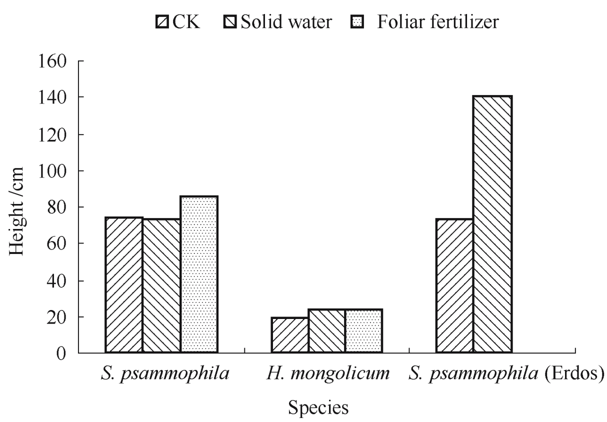

Fig. 1 Height of seedlings treated with solid water and foliar fertilizer

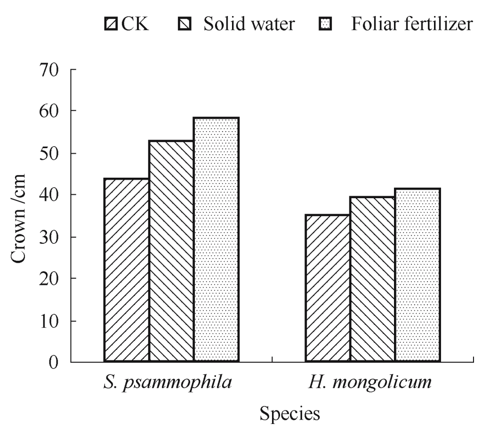

Fig. 2 Crown of seedlings treated with solid water and foliar fertilizer

Table 3 *F*-tests of height and crown treated with solid water and foliar fertilizer

Site	Species	Index	*SS*	*df*	*MS*	*F*	$p_r > F$	Significance
Changhannao	*S. psammophila*	Height	4,740.19	2	2,370.10	3.25	0.04	*
		Crown	4,861.97	2	2,430.99	4.10	0.20	ns
	H. mongolicum	Height	485.53	2	242.76	2.42	0.10	ns
		Crown	846.68	2	423.34	1.22	0.30	ns
Erdos	*S. psammophila*	Height	11,374.43	1	11,374.43	63.50	0.000,04	***

Note: * significant at $\alpha = 0.05$, and ** significant at $\alpha = 0.01$

field, the effect of solid water can reach highly significant levels ($p = 4.49 \times 10^{-5} \ll \alpha = 0.01$) for *S. psammophila* because Erdos is located in the Kubuqi desert and water is scarce; therefore, the effect of water on survival rates and growth is very remarkable.

4.3 Measurement of biomass

The biomass measurement results showed that solid water has a marked improvement on biomass of *S. psammophila* and *P.* cv. "Opera" in the Erdos field and analyses of variance indicate that there were significant differences (Figs. 3 and 4, Table 4). However, neither solid water nor foliar fertilizer treatments, although positive for biomass increment of *S. psammophila* and *H. mongolicum* in the Changhannao experimental field, were statistically significant. The differences of the two experimental fields showed that the drier the climate, the worse the soil moisture conditions and the rarer the vegetation, the better the soil water function, because seedlings can make full use of solid water, which can satisfy survival and growth of seedlings in the early stages. Foliar fertilizer was used only in the Changhannao field and its functions under different weather and soil conditions need further studies.

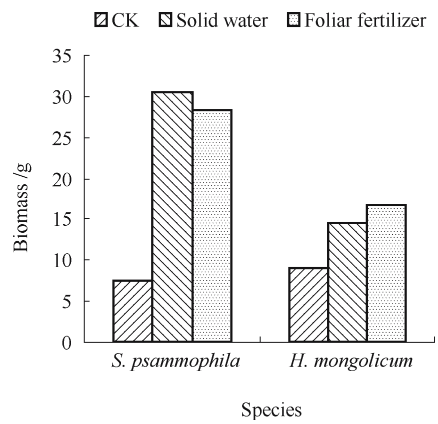

Fig. 3 Biomass of seedlings treated with solid water and foliar fertilizer in Changhannao

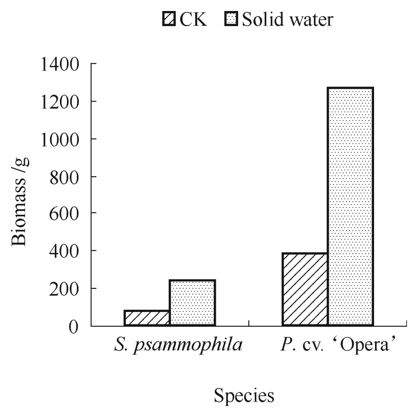

Fig. 4 Biomass of seedlings treated with solid water in Erdos

5 Conclusions

1) Application of solid water and foliar fertilizer in afforestation can clearly improve the survival rate of seedlings, especially in *S. psammophila*; the highest survival rates of *S. psammophila* and *H. mongolicum* were above 90% with 1 kg of solid water and 10 mg/kg of foliar fertilizer.

2) From the results of the two fields, we know that the functions of solid water were better in the Erdos desert than that in Changhannao. Solid water should be applied widely in barren sandy lands; effects of soaking roots with foliar fertilizer vary among several species, with the best treatment effects from cuttings.

3) Solid water provides moisture for plant roots through slow melting. Foliar fertilizer improves water absorption ability of plants, provides some nutrients for seedlings and consequently, strengthens metabolism and disease resistance

Table 4 *F*-tests of biomass with solid water and foliar fertilizer

Site	Species	*SS*	*df*	*MS*	*F*	$p_r > F$	Significance
Changhannao	*S. psammophila*	1,124.06	2	562.03	1.75	0.23	ns
	H. mongolicum	134.21	2	67.10	0.28	0.76	ns
Erdos	*S. psammophila*	72,692.68	1	7,2692.68	371.43	5.45×10^{-8}	***
	P. cv.'Opera'	193,943,4.00	1	193,943,4.00	1,885.32	8.73×10^{-11}	***

Note: ** significant at $\alpha = 0.01$

of seedlings. Afforestation technologies should be selected depending on different site conditions.

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