Postprint: Ecological Characteristics of Planted Haloxylon ammodendron Communities in the Gurbantüinggüt Desert

Authors: Ding Gaigai, Jiang Jin, Song Chunwu, Li Shengyu, Wang Haifeng, Zhou Jie, Li Yaping

Date: 2017-11-10T00:00:00+00:00

Abstract

To investigate the ecological characteristics of artificial Haloxylon ammodendron forest communities (relying on natural precipitation) in the Mosuowan area on the southern edge of the Gurbantunggut Desert over the past 33 years, this study conducted surveys and monitoring on the growth performance of Haloxylon ammodendron, herbaceous plants, and soil moisture in artificial Haloxylon ammodendron forests established through two afforestation techniques (snow-sand borrowing afforestation and autumn irrigation afforestation). The results indicate: Haloxylon ammodendron established through both snow-sand borrowing afforestation and autumn irrigation afforestation are growing well to date, with current plant heights and crown widths exceeding 2 m and 2 m², respectively, and current-year new shoot lengths exceeding 20 cm; initial survival rates of the planted Haloxylon ammodendron were relatively high at 40% and 63%, respectively; following natural regeneration, existing densities have increased in both cases, with the plantations forming uneven-aged, multi-layered mixed forests, and different dominant species of herbaceous plants growing in the understory; soil water content exceeds 2.00% in both cases, which can satisfy the growth requirements of Haloxylon ammodendron. Due to differences in land preparation methods and initial water supply between the two afforestation techniques, substantial differences exist in Haloxylon ammodendron growth, understory herbaceous plant coverage and diversity, and the number of naturally regenerated Haloxylon ammodendron individuals between the two forest types, with the overall condition of autumn irrigation afforestation sites being superior to that of snow-sand borrowing afforestation sites. Both afforestation techniques exhibit good adaptability to local ecological conditions; although snow-sand borrowing afforestation has relatively lower density, it is superior to natural vegetation conditions and has lower afforestation costs; autumn irrigation afforestation has higher density and more naturally regenerated indi-

viduals, but higher afforestation costs and slower later-stage growth, requiring certain artificial measures to adjust density. In summary, Haloxylon ammodendron established through both snow-sand borrowing afforestation and autumn irrigation afforestation are currently growing relatively stably, with the latter demonstrating stronger adaptability to the ecological conditions of this region.

Full Text

Ecological Characteristics of Cultivated Haloxylon ammodendron Communities in the Gurbantunggut Desert

DING Gaigai[1,2], JIANG Jin[1],, SONG Chunwu[1], LI Shengyu[1], WANG Haifeng[1], ZHOU Jie[1,2,3], LI Yaping[1,2]

[1]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]Cele National Station of Observation and Research for Desert-Grassland Ecosystems, Cele 848300, China

Abstract: To investigate the ecological characteristics of artificial Haloxylon ammodendron communities (rainfed) over 33 years in the Mosuowan area of the southern Gurbantunggut Desert, we monitored and surveyed the growth performance, herbaceous vegetation, and soil moisture of H. ammodendron plantations established using two afforestation techniques: snow-sand dressing and autumn irrigation. The results showed that: (1) H. ammodendron grew well under both techniques, with average plant height and canopy area exceeding 2 m and 2 m², respectively, and current-year shoot length >20 cm. Initial survival rates were relatively high at 40% and 63%, respectively. Natural regeneration increased stand density, forming uneven-aged, stratified mixed forests with different dominant herbaceous species in the understory. Soil water content exceeded 2.00% in both cases, sufficient for H. ammodendron growth. (2) Due to differences in site preparation and initial water supply, the two plantations differed significantly in H. ammodendron growth, understory vegetation cover and diversity, and natural regeneration density, with overall better conditions in autumn-irrigated plots. (3) Both techniques showed good adaptability to local ecological conditions. Although snow-sand dressing had lower density, it outperformed natural vegetation and had lower costs. Autumn irrigation produced higher density and more natural regeneration, but at higher cost and with slower later growth, requiring density adjustment measures. In conclusion, H. ammodendron growth was stable under both techniques, with autumn irrigation showing stronger adaptability to local conditions.

Keywords: Snow-sand dressing afforestation; Autumn-irrigated afforestation; Haloxylon ammodendron forest; Natural regeneration; Species diversity; Soil water content; Gurbantunggut Desert

Introduction

Artificial afforestation is an effective measure for desertification control and has played an important role in ecological restoration and reconstruction in northwestern China's desert regions. However, since the 1950s, artificial forest decline has been reported worldwide, and some plantations in China have also experienced degradation or even mortality. For example, some "Three-North" shelter forests have shown tree decline; poplar (Populus spp.) in the Hexi Corridor grows slowly or stagnates, becoming "stunted old trees" ; and Pinus sylvestris var. mongolica in the Horqin Sandy Land has experienced partial mortality. The main cause is incomplete adaptation between tree species selection, planting techniques, and local ecological conditions.

The Gurbantunggut Desert is China's second-largest desert, dominated by fixed and semi-fixed dunes. Since the 1980s, climate change and human disturbance have caused severe degradation of natural vegetation, with coverage significantly reduced to below 5% in some areas, leading to desert activation. The Mosuowan area on the southwestern edge is a typical region of dune activation, where a 10–20 km wide and 80 km long belt of activated dunes has formed, mostly evolving into mobile dunes that invade oases and bury farmland, seriously endangering agricultural production, livelihoods, and the ecological environment. In 1984, scientists from the Xinjiang Institute of Biology, Soil and Desert Sciences (now Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences) conducted trials of autumn-irrigated and snow-sand dressing afforestation techniques, successfully establishing artificial H. ammodendron forests that stabilized activated dunes, improved regional ecological conditions, and ensured oasis ecological security. These techniques were subsequently promoted regionally, contributing to ecological restoration.

Mosuowan has an arid desert ecosystem with scarce and highly variable precipitation. Snow-sand dressing afforestation relies entirely on natural precipitation since planting, while autumn-irrigated afforestation only received artificial irrigation during the first four years. Therefore, critical questions remain about whether soil moisture can support normal H. ammodendron growth under long-term rainfed conditions, the status of community ecological characteristics, and the reliability and sustainability of these techniques for regional application. These issues are key to evaluating the adaptability of afforestation techniques to local conditions.

This study analyzed eight years of soil moisture monitoring data, 2016 stand age-class distribution, and 2016 understory vegetation composition to clarify the ecological characteristics of 33-year-old artificial H. ammodendron communities and discuss the similarities, differences, and functional sustainability of the two techniques, providing a scientific basis for evaluating afforestation technique suitability in arid regions.

1. Study Area Description

Mosuowan (45°03 N, 86°06 E, elevation 314 m) lies on the southwestern edge of the Gurbantunggut Desert and has a typical continental arid desert climate. Annual precipitation is 114.89 mm, annual evaporation 1,942.1 mm, aridity index 16.9, mean annual temperature 4–6°C, 10°C accumulated temperature 3,000°C, and annual sunshine duration 3,100–3,200 h. Spring and summer are windy seasons, with maximum wind speeds reaching 20 m·s ^{1}. Winter snow depth is about 13 cm, reaching up to 27 cm. When temperatures rise in spring, snow melt and increased precipitation raise soil moisture. The zonal soil is desert sierozem, with some alkalinization.

Snow-sand dressing afforestation utilizes moist sand layers for planting. On natural drifting sand, surface snow is swept into piles in early spring. After melting, planting pits (>60 cm diameter) are dug through the dry sand layer, H. ammodendron is planted, and moist sand is backfilled. Initial planting density was 667 plants·hm ^{2}, with no irrigation for 33 years [Figure 1: see original paper].

Autumn-irrigated afforestation involves mechanical site leveling in autumn, followed by irrigation before spring planting. After leveling, plots (3–10 m wide) with ditches (4–5 m spacing) were flood-irrigated (1,000–1,400 m^3·hm ^{2}) or ditch-irrigated (750–900 m^3·hm ^{2}) in October. Planting density was 2,500 plants·hm ^{2} in March. The plantation received annual autumn irrigation (1,500 m^3·hm ^{2}) for the first four years (1984–1987), then no irrigation for 29 years [14] [Figure 1: see original paper].

2. Methods

In April 2016, four 10 m × 10 m survey plots (A1–A4) were established around long-term soil moisture observation points in the snow-sand dressing plantation, selecting areas with similar growth and density, spaced >50 m apart. Similarly, four 10 m × 10 m plots (B1-B4) were set up in the autumn-irrigated plantation. All H. ammodendron individuals were numbered (except 2016 seedlings). Five 1 m × 1 m herbaceous subplots were established diagonally in each plot to survey understory vegetation [Figure 2: see original paper].

2.1 Population Structure and Growth In May 2016, living individuals were counted to calculate survival rates relative to initial planting densities. From April to October, 17 standard trees per plot were selected (based on rows, height, and basal diameter) and tagged. Height (cm) and canopy diameter (cm) were measured periodically with steel tapes. Fifteen new shoots per tagged tree were measured for growth. Values from four plots were averaged.

2.2 Age-Class Structure Previous studies show that among height, canopy, and basal diameter, height has the lowest coefficient of variation and best reflects age [15–17]. Therefore, height was used for age-class classification. In

July 2016, all H. ammodendron heights were measured. Using 40 cm intervals, individuals were divided into six age classes (I–VI). The proportion of each age class was calculated. From April to November 2016, new seedlings were recorded periodically to calculate survival and mortality rates.

2.3 Understory Vegetation Survey From April to June 2016, understory herbaceous species, individual counts, height, and canopy were recorded. Vertical photographs of subplots were taken with digital cameras, and Image Pro Plus software was used to calculate vertical projection area percentages to determine vegetation cover (%), averaged across subplots.

2.4 Soil Water Content Measurement From 2009–2016, soil samples were collected monthly (mid-month) from April to October using augers at 0–120 cm depth in 10 cm increments. Fresh weights were measured with a 1/1,000 electronic balance, then oven-dried at 105°C for 8 h to determine water content.

2.5 Data Analysis Origin 8.0 was used for plotting, and SPSS 20.0 for significance testing (non-parametric tests) and Pearson correlation analysis. Diversity indices included importance value, richness index R, and -diversity [Shannon-Wiener index (H), Simpson index (D), Pielou evenness index (Jsw and Jsi)], calculated following Chen et al. [18].

3. Results

3.1.1 Survival Rate of Planted H. ammodendron Based on surveys of the largest surviving individuals and initial planting densities, current survival rates were only 40% for snow-sand dressing but higher at 63% for autumn irrigation.

3.1.2 Growth and Current-Year Shoot Elongation Under both techniques, H. ammodendron height increased gradually from April to October [Figure 3: see original paper]. Mean heights in 2016 were 2.43 m (snow-sand dressing) and 2.35 m (autumn irrigation). The August height decrease in snow-sand dressing resulted from wind breakage of two 3.2 m tall individuals. Mean canopy areas were 2.46 m^2 and 2.70 m^2, respectively, with fluctuating monthly growth (due to measurement errors and rodent herbivory) but overall increasing trends [Figure 3: see original paper].

Current-year shoot growth increased gradually [Figure 4: see original paper], with snow-sand dressing significantly greater than autumn irrigation each month (except April–May) ($P<0.05$). Maximum growth occurred at season's end: 39.08 cm in September for snow-sand dressing and 28.49 cm in August for autumn irrigation (declining to 24.31 cm in September due to powdery mildew).

3.1.3 Stand Age-Class Structure Population structure reflects size/age distribution [19]. Stand densities were 825 plants · hm ² (snow-sand dressing) and

3,600 plants·hm ^{2} (autumn irrigation), both exceeding initial densities. Age-class proportions are shown in [Figure 5: see original paper]. Young individuals (classes I–IV) represent natural regeneration. The ratio of young to old individuals (classes V–VI) indicates regeneration capacity: 0.8:1 for snow-sand dressing and 1.13:1 for autumn irrigation, showing good natural regeneration, stronger in autumn-irrigated plots.

Among young individuals, class II dominated, comprising 47% and 59% of populations, respectively, indicating variable annual recruitment with successful seedling establishment in wet years, forming competitive cohorts and healthy population structures.

3.1.4 Seedling Survival Seedling survival curves [Figure 6: see original paper] showed low summer survival, with few reaching season' s end. By mid-November, survival was 41.0% for snow-sand dressing and 53.4% for autumn irrigation.

3.2 Understory Herbaceous Diversity Understory vegetation is crucial for desert stabilization and sand fixation [20], driving stand structure adjustment and site productivity recovery [21]. Both plantations were dominated by Chenopodiaceae with many ephemerals. Species richness was higher in snow-sand dressing plots. Spring dominants were *Tetracme quadricornis*, *Salsola ruthenica*, and *Lappula semiglabra* with similar importance values; autumn dominant was *Agriophyllum squarrosum*. In autumn-irrigated plots, spring dominants were *Corispermum orientale*, *Atriplex patens*, and *Malcolmia scorpioides* (with *C. orientale* absolutely dominant); autumn dominant was *Ceratocarpus arenarius*.

Understory cover was 25.12% (snow-sand dressing) and 32.23% (autumn irrigation), exceeding the 14% threshold for sand surface stability [22]. -diversity differed: Simpson and Pielou indices were similar, but Shannon-Wiener index was lower in autumn-irrigated plots .

3.3.1 Soil Water Vertical Distribution Eight-year average soil moisture profiles [Figure 7: see original paper] differed markedly. Snow-sand dressing moisture increased with depth then stabilized, while autumn irrigation showed fluctuations with clear inflections at 30 cm, 50 cm, and 70 cm. Autumn irrigation had higher moisture in 0–30 cm and 70–100 cm layers (2.00% and 2.99%) compared to snow-sand dressing (1.57% and 2.63%). Moisture ranges were 1.05%-2.82% (snow-sand dressing) and 1.66%-3.24% (autumn irrigation), with similar means (2.29% vs. 2.30%). Variability was greater for snow-sand dressing (CV=0.49) than autumn irrigation (CV=0.22), indicating more stable moisture in the latter.

3.3.2 Soil Water Temporal Variation Annual average moisture (2009-2016) [Figure 8a: see original paper] showed snow-sand dressing was strongly influenced by precipitation, with both plantations showing significant positive correlations between precipitation and 0–70 cm (autumn irrigation) or 0–120 cm (snow-sand dressing) soil moisture. Annual moisture ranges were 1.04%–3.92% (snow-sand dressing) and 1.68%–3.00% (autumn irrigation), with greater interannual fluctuation in the former. Mean moisture was slightly higher in autumn irrigation (2.30% vs. 2.18%).

Monthly moisture and precipitation were not significantly correlated [Figure 8b: see original paper]. Both plantations showed decreasing moisture from April to September, with slight recovery in October. In the dry year 2015 (precipitation 81.65 mm vs. multi-year mean 114.89 mm), minimum moisture was 0.45% (CV=0.58) for snow-sand dressing and 1.41% (CV=0.14) for autumn irrigation. Thus, during low rainfall periods (2013–2015; July–October), autumn irrigation maintained higher moisture, demonstrating stronger drought resistance.

4. Discussion

4.1 Causes of Ecological Differences Between Plantations Differences in ecological characteristics clearly relate to afforestation techniques. Initial four-year irrigation in autumn-irrigated plots added fine particles, increasing soil clay content to 3.95% and improving water retention. Level terrain distributed precipitation evenly, and well-developed biological soil crusts (60% cover) reduced evaporation. High planting density also shaded soil, significantly increasing 0–30 cm moisture and favoring herbaceous recovery and seedling establishment, with lower seedling mortality. During drought, moisture decline was smaller, showing stronger resistance. However, high H. ammodendron density and understory cover reduced light, limiting species and lowering diversity indices [24].

Snow-sand dressing plots were planted directly on drifting sand with undulating terrain and weak water retention, relying solely on limited precipitation. Low planting density prevented water-plant imbalance. High evaporation reduced moisture content, survival, and seedling establishment, with lower understory cover but higher species richness.

Current H. ammodendron growth was better in snow-sand dressing, possibly due to intense water competition at high density in autumn-irrigated plots. Powdery mildew in some autumn-irrigated individuals may also relate to density, requiring further study. Management should consider density adjustment through selective thinning to improve growth quality and diversity.

4.2 Growth Adaptability of Rainfed H. ammodendron on Drifting Sand Tree survival is only a basic criterion for afforestation success; sustained growth and ecological function are essential. Natural regeneration is a key factor affecting species composition, structure, and dynamics, crucial for population development, community stability, and succession [29], and an important indicator of plantation sustainability. Some artificial H. ammodendron forests in Gansu and Inner Mongolia have experienced severe soil moisture decline, growth inhibition, and mortality, compromising function and sustainability [26–28].

In 1983, local shrub H. ammodendron was used to restore degraded vegetation and prevent wind damage in Mosuowan. After 33 years, plantations maintain high survival, large canopies, good current-year shoot growth, and increasing height. Natural regeneration of various ages increased stand density, forming uneven-aged mixed forests [31–32] with well-developed understory vegetation and biological crusts, providing effective windbreak and sand fixation.

Soil moisture is decisive for sand-fixing vegetation in arid/semi-arid regions. Although H. ammodendron is extremely drought-tolerant, growth is affected by aridity. Ma et al. [30] found normal growth requires >1.30% water content, mortality occurs at <0.82%, and minimal growth occurs at 0.82%–1.30%. In these rainfed plantations, profile-average moisture remained >2%, supporting normal growth, reproduction, and seedling establishment. Natural regeneration indicates environmental adaptation, with moisture as a prerequisite. Better moisture conditions in autumn-irrigated plots enhanced regeneration capacity.

Natural precipitation shows high interannual and intra-annual variation (CV=0.35 and 0.32). Soil moisture variability was greater in snow-sand dressing (CV=0.48 and 0.29) than autumn irrigation (CV=0.17 and 0.12). Thus, afforestation technique affects climate adaptation: low vegetation cover in snow-sand dressing caused greater moisture fluctuation than precipitation, while high cover in autumn irrigation reduced evaporation and enhanced drought adaptation. From the perspective of extreme drought adaptation, autumn irrigation demonstrates stronger adaptability.

Conclusion

In 1983, H. ammodendron was successfully established on drifting sand at Mosuowan. After 33 years, plantations show good natural regeneration, increased density, high initial survival, and understory cover >20%, providing effective sand fixation. Autumn irrigation maintains better moisture during droughts, with stronger resistance and higher vegetation carrying capacity than snow-sand dressing, though height and shoot growth are lower. Both techniques support functional sustainability in terms of survival, regeneration, growth, understory recovery, and soil moisture.

Good performance resulted from scientific selection of species, site conditions, and density. The Gurbantunggut Desert is typical H. ammodendron habitat, where this species is strongly adapted with high regeneration capacity. Stable winter snow increases spring soil moisture during the germination season, and frequent March–May precipitation provides good conditions for establishment.

Both techniques have advantages and disadvantages. Autumn irrigation effectively improves moisture and soil texture, increasing survival and carrying capacity, but is costly and labor-intensive, requiring later density management. Snow-sand dressing is a cost-effective, locally adapted method but has lower survival and weaker natural regeneration.

References

[1] Zhu J J. A review of the present situation and future prospect of science of protective forest[J]. Chinese Journal of Plant Ecology, 2013, 39(9): 872–888
[2] Bai F M, Dai C D, Chen C Z, et al. Progress of research on worldwide protection-forest[J]. Hunan Forestry Science & Technology, 2010, 37(5): 8–14
[3] Li X F, Su L, Zhang J X, et al. Spatiotemporal variation characteristics and influencing factors of protection forests after their 30 years construction in Northwest Shanxi Province of China[J]. Chinese Journal of Ecology, 2013, 32(9): 2382–2389
[4] Zhu J J, Li F Q. Forest degradation/decline: Research and practice[J]. Chinese Journal of Applied Ecology, 2007, 18(7): 1601–1609
[5] Zhang Z X, Liu L M, Jia Y, et al. Climatic ecological adaptation of shelter forests in Three-North Regions[J]. Chinese Journal of Ecology, 2009, 28(9): 1696–1701
[6] Liao K T, Man D Q, Zhang J C, et al. Contemporary situation of oasis shelterbelts and developing tendency in Hexi Corridor[J]. Journal of Northwest Forestry University, 2006, 21(5): 17–21
[7] Bai X F, Han H, Zhou F Y, et al. Analysis on dynamic change of relative water content and needle water conservation of Pinus sylvestris var. mongolica on sandy land[J]. Protection Forest Science and Technology, 2008, (3): 51–53
[8] Xia X C, Li C S, Zhou X J, et al. Desertification and Sandstorm Disaster in Xinjiang[M]. Beijing: Science Press, 1991
[9] Huang P Y, Lü Z L. Studies on establishment of Mosouwan oasis and the variation of sacsaoul desert[J]. Journal of Arid Land Resources and Environment, 1995, 9(4): 173–179
[10] Jia Y M, Liu T, Luo C, et al. Comparative study on the spatial heterogeneity of four shrub species in southern marginal zone of the Mosuowan desert[J]. Arid Zone Research, 2008, 25(2): 225–230
[11] Chinese Academy of Sciences. The miracle of desert hinterland[EB/OL]. (2010-10-26). http://www.cas.cn/kxcb/kpwz/201010/t20101026_2993438.shtml.
[12] Zhang L Y, Cui W C. The main characteristics of oasis ecotope and its protection in the farm of 150th corps[J]. Arid Zone Research, 1990, 7(1): 11–17
[13] Qian Y B, Li Y F. Study on soil physical properties of desertified land in Mosuowan reclamation area[J]. Arid Zone Research, 1999, 16(2): 41–46
[14] Li Y F, Yang G. Studies on the moisture balance of Haloxylon ammodendron sand-break forest: I. the moisture state of Haloxylon ammodendron autumn irrigated sand-break forest[J]. Arid Zone Research, 1996, 13(2): 44–50
[15] Wang W, Liang C Z, Zhu Z Y, et al. Studies on the measuring method of growth rings of Haloxylon Ammodendron and its growing dynamics[J]. Journal of Arid Land Resources & Environment, 2001, 15(2): 67–74
[16] Li J G, Ning H S, Liu B. Study on character structure and distribution pattern of Haloxylon ammodron[J]. Journal of Xinjiang Agricultural University, 2003, 26(3): 51–54

[17] Huang P Y, Li Q J, Yuan Q F. Effects of climate change on Haloxylon ammodendron community in southern edge of Zhunger Basin[J]. Acta Ecologica Sinica, 2008, 28(12): 6051-6059
[18] Chen S Y, Liu W J, Ye B S, et al. Species diversity of vegetation in relation to biomass and environmental factors in the upper area of the Shule River[J]. Acta Prataculturae Sinica, 2011, 20(3): 70-83
[19] Liu G J, Zhang X M, Zhu J T, et al. Structure and dynamics of Haloxylon ammodendron population along the southeastern margin of the Zhunger Basin[J]. Acta Botanica Boreali-Occidentalia Sinica, 2011, 31(6): 1250-1256
[20] Li Q M, Zeng Y, Sun Q M, et al. Precipitation in May is a key factor to determinate the distribution of ephemeral plants in Gurbantünggüt Desert[J]. Chinese Journal of Ecology, 2014, 33(8): 2038-2045
[21] Kang B, Liu S R, Cai D X, et al. Effects of Pinus massoniana plantation stand density on understory vegetation and soil properties[J]. Chinese Journal of Applied Ecology, 2009, 20(10): 2323-2331
[22] Wang X Q, Jiang J, Lei J Q, et al. The distribution of ephemeral vegetation on the longitudinal dune surface and its stabilization significance in the Gurbantunggut Desert[J]. Acta Geographica Sinica, 2003, 58(4): 598-605
[23] Xu X Y, Yan P, Guo S J, et al. The interception loss of rainfall by three sand-fixing shrubs at the fringe of Minqin Oasis[J]. Journal of Desert Research, 2013, 33(1): 141-145
[24] Zou Y, He K N, Zhao C, et al. Relationship between plantation density and the plants diversity under forest of Picea crassifolia in Alpine region[J]. Acta Botanica Boreali-Occidentalia Sinica, 2013, 33(12): 2543-2549
[25] Zeng D H, Jiang F Q, Fan Z P, et al. Stability of Mongolian pine plantations on sandy land[J]. Chinese Journal of Applied Ecology, 1996, 7(4): 337-343
[26] Zhang J C, Ji Y F, Wang F L, et al. Rain-fed recovery of degenerated artificial Haloxylon ammodendron population in Minqin[J]. Journal of Northwest Forestry University, 2010, 25(1): 77-81
[27] Huang Z C, Liu J Q, Lu Z M, et al. Preliminary research in the cause of Haloxylon ammodendron degredation in Minqin[J]. Scientia Silvae Sinicae, 1983, 19(1): 82-87
[28] Zhang X L. Studying on the cause of Haloxylon ammodendron degredation and conservation[J]. Inner Mongolia Forestry Science & Technology, 1999, (2): 1-3
[29] Li X S, Peng M C, Dang C L. Research progress on natural regeneration of plants[J]. Chinese Journal of Ecology, 2007, 26(12): 2081-2088
[30] Ma Q L, Wang J H, Zhu S J. Effects of precipitation, soil water content and soil crust on artificial Haloxylon ammodendron forest[J]. Acta Ecologica Sinica, 2007, 27(12): 5057-5067
[31] Carnevale N J, Montagnini F. Facilitating regeneration of secondary forests with the use of mixed and pure plantations of indigenous tree species[J]. Forest Ecology and Management, 2002, 163(1/3): 217-227
[32] Wang H S. Natural regeneration of plantation forests under drought[J]. Arid Zone Research, 2012, 29(5): 743-750