Case study on woody plant introduction into white oasis soil under limited watering in Inner Mongolia, China

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Abstract: White oasis soil, which is widely distributed in the Inner Mongolia Autonomous Region of China, prevents the growth of root systems by forming an impermeable layer of hard calcium carbonate, and therefore is not suitable for plant growth. Consequently, it is difficult to restore the ecology once the land is devastated. Efforts to restore or reproduce the ecology in this region by continuously planting and watering large seedlings have had little success. Therefore, this study examined how to introduce woody plants into white oasis soil under limited watering conditions. For this study, nursery block seedlings of eight tree species were planted to compare their compatibility with white oasis soil. As a result, regarding the compatibility with white oasis soil, the survival rate one year and two months after planting was highest at 98% for *Ulmus pumila* L., 85% for *Syringa oblata* Lindl., 52% for *Prunus persica* (L.) Batsch, and 40% or less for the other five tree species. The result of the above test suggests the possibility of introducing woody plants into white oasis soil under limited watering conditions by planting *U. pumila*, *S. oblata*, *P. persica* and other tree species highly compatible with white oasis soil.

Key words: White oasis soil, Planting, Limited watering, Nursery block seedling

大林 直・浅見和弘・陸志成・安孔建・賀永 明・齋藤 大・劉瑛・山寺喜成：中国内モンゴル自治区の白干土における低灌水条件下での樹木導入試験

摘要：中国内モンゴル自治区に広く分布する白干土は、固い炭酸カルシウムの不透水層を形成し根系の伸長を阻害するなど、植物の生育には不向きである。このため、土地が荒廃化しても生態環境の修復は困難となっている。現地では、大苗を植栽し多量の灌水を継続的に行っているが、生態環境の修復再生はほとんど進んでいない。そこで、本報告では、白干土において低灌水条件下で

保育ブロック苗を用いて樹木を導入する手法を検討した。白干土への適合性の高い樹種は、施工1年2か月後の活着率をみるとニレ (*Ulmus pumila* L.) が最も高い97.8%を示し、ライラック (*Syringa oblata* Lindl.) が84.4%、モモ (*Prunus persica* (L.) Batsch) が52.3%、他の5種類の樹木の活着率は40%以下だった。白干土に適合性の高い *U. pumila* (ニレ)、*P. persica* (モモ)、*S. oblata* (ライラック) などの樹種を植栽することにより、白干土において低灌水条件下で樹木を導入することが可能であるとの見通しを得た。

キーワード：白干土、樹木導入、低灌水、保育ブロック

1. Introduction

White oasis soil is a calcium alkaline soil, which is widely distributed in the Inner Mongolia Autonomous Region of the People's Republic of China. Calcium carbonate contained in the soil easily consolidates to form a hard impermeable layer (hereinafter referred to as "calcium carbonate accumulation layer" that inhibits the growth of root systems and consequently the growth of local plants (Araya *et al.*, 2003). The Inner Mongolia Autonomous Region, which makes up 28% of the total desert area in China (Wu, 2009), is a main source of yellow sand. The occurrence of strong winds over 17 m s⁻¹ erodes the surface soil and accelerates the devastation of the land (Wang, 2010). Therefore, it is considered important to restore the vegetation by introducing woody plants while creating a suitable environment for this purpose by developing wind buffer zones such as windbreaks.

The Chinese government actively plants *Pinus* L. and

Populus L. in the white oasis soil region for the restoration of ecology (Dongwuzhumuqinqi government website, 2004). However, since the conventionally used large seedlings have their taproots cut, they do not root deep in the ground and therefore can only absorb water from a narrow range. Consequently, they need abundant watering after being planted. In the area of our field survey, it was often observed that most of the seedlings had withered and died even after watering. In addition, in semiarid areas such as the Inner Mongolia Autonomous Region, too much watering can result in lower groundwater levels, salt damage (Qu, 2009), and further deterioration of the ecology.

This study examined how to introduce woody plants into white oasis soil under limited watering conditions in accordance with the natural environment of such regions. It is considered that the reason why plant growth is restricted under white oasis soil is mainly because the roots of the plants cannot grow sufficiently due to the poor air permeability of the calcium carbonate accumulation layer, high soil hardness, and other physical properties of the soil. We examined what tree species which can establish in this area using nursery block seedling with success examples by little watering. This study compared the compatibility of eight tree species with white oasis soil.

2. Study area

The test was conducted in Dongwuzhumuqinqi, Xilingol League, Inner Mongolia Autonomous Region, where white oasis soil is distributed. Dongwuzhumuqinqi is located at 45° 29' 54" north latitude and 116° 58' 22" east longitude in the northeastern area of Xilingol League, and belongs to the steppe climate region. The elevation is 800 to 1,500 m (Fig. 1). According to the website of the popular government of Dongwuzhumuqinqi (Dongwuzhumuqinqi government website, 2016), the annual highest temperature is 39.7°C, annual lowest temperature is -40.7°C, annual average temperature is 1.6°C, average temperature of the warmest month (July) is 21.0°C, and average temperature of the cold-

est month (January) is -18.9°C. The annual precipitation is around 300 mm, 70% of which occurs from June through August. The annual evaporation from soil is over 3,000 mm, which is ten times the annual precipitation. The average wind speed is 3.6 m s⁻¹, and the maximum instantaneous wind speed, 34.0 m s⁻¹.

The test site was set at a flat land area of approx. 50 × 75 m in Dongwuzhumuqinqi. Around the test site, *Oryzoideae* spreads, and goats, sheep, and cows graze, whereas inside the test site, *Artemisia* L. dominates. According to on-site hearing surveys, barley, field mustard, and potatoes were once cultivated in the test site, but the site has been left unused since 2012 due to decreased crop yields. It is considered that *Artemisia* L. increases instead of *Oryzoideae* in wastelands, which is not desirable for grazing.

Figure 2 shows the results of the soil profile investigation of the test site carried out as a preliminary survey in August 2013. The thickness of the surface soil is approx. 30 cm, and the calcium carbonate accumulation layer is distributed with a thickness of approx. 80 cm between a depth of 30 cm and 80–120 cm. Also, there is a sand and pebble layer under the calcium carbonate accumulation layer. The gas phase rate and coarse pore rate of the calcium carbonate accumulation layer are 27% and 5%, respectively. The soil hardness measured with a Yamanaka soil hardness meter (Pocket type, Fujiwara Scientific, Tokyo, Japan) is 27 ± 1.7 mm, and the saturated hydraulic conductivity is 3.3 × 10⁻⁷ cm s⁻¹. The moisture contained in white oasis soil was approx. 7% at a depth of 10 cm, approx. 10% at 20 cm, approx. 7% at 50 cm, and approx. 7% at 70 cm, when measured with a soil moisture meter (CS620, Campbell Scientific, Utah, USA). The root systems of the plants are easily found in the surface soil, but rarely found in the calcium carbonate accumulation layer.

Around the test site, seedlings are planted in combination with large-scale planting hole digging such as fish scale pitting (Fig. 3) in order to restore the ecology in the mountain areas, *Pinus tabulaeformis* Carr., *Pinus sylvestris* L. var. *mongolica* Litv., *Prunus ansu* Kom., *Prunus davidiana* (Carr.) Franch., and *Syringa oblata* Lindl. are planted in hilly areas, and *Populus* and *Ulmus pumila* L. are planted in flatlands.

Fig. 1 Location of study area in Dongwuzhumuqinqi

Fig. 2 Soil morphology of study area

Fig. 3 Fish scale pit

However, abundant watering is required to grow seedlings. According to the local staff, a total of over 2,000 L of watering, more than 15 times per year is required for each street tree seedling.

3. Methods

3.1 Preparation of Nursery Trees

The conventionally used seedlings have their taproots cut at the raising stage, and therefore do not root deep in the ground regardless of the hardness of the soil. Consequently, they can only absorb water from a narrow range, and are therefore vulnerable to dryness and need abundant watering after being planted (Yamadera, 2014). This test used nursery blocks in which the taproots had not been cut at the raising stage and therefore were able to grow deep in the ground. Figure 4 shows the shape of the nursery block, the seedling raising stage (nursery block seedlings), and the planting outline.

The nursery block is a cylindrical soil block having a through hole and shallow grooves in the center (Chinese patent number: CN125571C), and the nursery block seedling is prepared by planting and growing the nursery block with its through hole filled with culture soil (Chinese patent number: CN101433167B). The nursery block protects the plant during the initial growing stage and guides the taproot deep in the ground along the through hole (Yamadera *et al.*, 2002; Furubayashi *et al.*, 2003; Nishikawa *et al.*, 2004). It can also retain water and reduce withering of plants by decelerating the soil drying speed to slower than the growing speed of the root systems (Yamadera, 2010). Nursery blocks are confirmed to be applicable to the Kubuqi Desert, the Loess Plateau, and other devastated hilly areas in China where the annual precipitation is 400 mm or less (Obayashi *et al.*, 2010; Saito *et al.*, 2010; Yamadera, 2010).

In this test, a base soil was prepared by mixing surface soil, cow dung, and clay at a ratio of 18 : 18 : 2, mixing a compound fertilizer (N : P = 15 : 42) into the base soil at a rate of 2 g of fertilizer to 1 L (approx. 1 kg) of the base soil,

Fig. 4 Summary of nursery block seedling

Fig. 5 Construction process of nursery block seedling

and then forming the mixture into nursery blocks using exclusive equipment. The nursery block seedlings were used after being planted in a plastic greenhouse beside the test site and grown for about three to four months.

3.2 Planting Test of Eight Tree Species

Figure 5 shows how the nursery block seedling was planted. First, planting holes 12 cm in diameter and 60 cm in depth were dug using an electric auger. Each hole was back-filled with a mixture of dug-out soil and 50 g of compound fertilizer (N : P : K = 15 : 15 : 15) to a depth of 50 cm, and then 3 L of water was poured into the hole. After the 3 L of water permeated into the soil, an additional 2 L of water was poured in, and then dug-out soil was added and agitated to form slurry. Then, a nursery block seedling was planted by inserting it into the slurry.

Eight tree species selected from those widely planted in northern China (Inner Mongolia Quality and Technical Supervision Bureau, 2003) were planted. The eight tree species adopted were *Platycladus orientalis* (L.) Franco, *U. pumila*, *P. ansu*, *Prunus persica* (L.) Batsch, *Robinia pseudoacacia* L., *Acer truncatum* Bunge, *Fraxinus chinensis* Roxb., and *S. oblata*. Forty-one (41) to 50 seedlings were planted in a row by tree species in the north-south direction. The number of seedlings of each tree species was 42 for *P. orientalis*, 45 for *U. pumila*, 130 for *P. ansu*, 44 for *P. persica*, 45 for *R. pseudoacacia*, 88 for *A. truncatum*, 131 for *F. chinensis*, and 45 for *S. oblata*; therefore, the total number of seedlings was 533. The interval between seedlings and that between rows were both 1 m. Seedlings were planted in a zigzag pattern with those planted in the adjacent rows.

Seedlings were planted from August 3 to August 6, 2014.

Two liters of water was fed to each seedling in April 2015, but after that, watering was not performed until October 7, 2015.

3.3 Survey items

After the planting described above, the survival rate, tree height, and root shape were surveyed. Surveys were conducted on August 6, August 23, and October 4, 2014, and on July 23, August 15, August 20, and October 7, 2015. However, only the root shape was surveyed on August 19, 2015. However, goats invaded the test site during the observation period from August 15 to October 7 in 2015, and four species of trees suffered damage. The goats ate the tip portions such as terminal buds and side buds of four species, *U. pumila*, *P. ansu*, *P. persica*, and *S. oblata*, resulting in a decrease in the average tree height. On the other hand, *P. orientalis* was not damaged by goats.

The Mann-Whitney U test was performed for the average measurements of each survey item in order to check for significant differences. The significance level was less than 5% ($p < 0.05$).

4. Results

Figure 6 shows the changes in the survival rate of the eight tree species. The survival rate as of October 7, 2015, which is approx. one year and two months after the planting, was highest at 98% for *U. pumila*, next highest at 84% for *S. oblata*, 52% for *P. persica*, 30% for *P. ansu*, and lowest at 12% for *P. orientalis*. The survival rate was confirmed to have decreased for all the tree species after passing the winter, and all individuals of *R. pseudoacacia*, *A. truncatum* and *F. chinensis* had withered and died. On the other hand, no conspicuous decrease was observed in the survival rate in the summer season from July 23 to August 15, 2015.

Figure 7 shows the changes in the average tree height of the eight tree species. The changes in the average tree

Fig. 6 Changes in woody plant survival rate from August 2014 to October 2015. (n) means the number of individuals at the planting date.

height of the eight tree species are roughly classified into three types. The first is *U. pumila*, *P. persica*, and *S. oblata* in which the tree height did not decrease, but consistently increased (Group 1). The second is *P. orientalis* and *P. ansu* in which twigs had withered in the winter and the tree height had decreased (Group 2). The third is *R. pseudoacacia*, *A. truncatum* and *F. chinensis* in which all individuals were confirmed to have withered and died in 2015 (Group 3).

The average tree height of *P. persica* in Group 1 was 12.8 ± 6.4 cm at the time of planting, and 13.4 ± 6.4 cm as of October 4, i.e., two months after the planting, and therefore no significant increase was observed, but the average tree height as of July 23, 2015 was 20.0 ± 8.3 cm, which shows a significant increase from the tree height as of October 4. After that, however, the average tree height did not increase significantly until August 15. The average tree height decreased to 13.7 ± 5.2 cm as of October 7, due to vermin damage by a goat. Also, *U. pumila* and *S. oblata* grew slightly just after the planting, but grew significantly after passing the winter, from October 4, 2014 to July 23, 2015. The increase in the average tree height approx. one year from the planting to October 7, 2015 was 10.8 cm for *P. persica*, 7.5 cm for *U. pumila*, and 4.1 cm for *S. oblata*.

The average tree height of *P. orientalis* in Group 2 was 8.7 ± 2.0 cm at the time of planting, and 9.8 ± 1.8 cm as of October 4, i.e., two months after the planting, and therefore no significant increase was observed. Furthermore, twigs had withered during the winter, and the average tree height decreased to 3.4 ± 1.9 cm by July 23, 2015, and did not increase significantly after that. The average tree height one year after the planting was 4.4 ± 2.2 cm, which is lower than 8.7 ± 2.0 cm, i.e., the tree height at the time of planting. The same applies to *P. ansu*.

Fig. 7 Changes in woody plant tree height from August 2014 to August 2015 (mean $\pm$ SD).

(n) means the number of individuals at the planting date. Planting date: August 3–6, 2014

— means that all individuals withered and died. Values with different letters are significantly different.

The average tree height of *R. pseudoacacia* in Group 3 was 12.8 ± 3.2 cm at the time of planting, and 14.4 ± 3.4 cm as of October 4, i.e., two months after the planting, and therefore a tendency to increase was observed. However, all the individuals withered and died during the winter. The same applies to *A. truncatum* and *F. chinensis*.

Groups grow roots system was the same of the changes in the average tree height. Figure 8 shows photographs of the root systems of *U. pumila*, which had grown well (Group 1), *P. ansu* for which the average tree height had decreased during the winter (Group 2), and *F. chinensis* for which all the individuals had withered or died (Group 3). Both the taproots and lateral roots of *U. pumila* had grown, and the taproots had grown to a depth of 40 cm. The roots of *P. ansu* had grown wide in the horizontal direction, but only to a depth of approx. 25 cm in the vertical direction. The roots of *F. chinensis* had not grown to the outside of the nursery blocks.

5. Conclusion

Planting eight tree species, this study confirmed that the survival rate was higher than 50%, and the tree height had increased for *U. pumila*, *P. persica* and *S. oblata*. (Figs. 6 and 7). Regarding the root systems of *U. pumila*, for which the survival rate was high and the tree height had increased, the taproots had grown, and the lateral roots had grown wide diagonally downward. On the other hand, regarding *P. ansu*, rootage was partly confirmed and the root systems had grown to a depth of 25 cm, but there were few roots and they had grown only in a narrow range. The roots of *F. chinensis* had not grown at all, but had withered and died (Fig. 8). In the preliminary soil profile investigation, there was no difference in the soil moisture by the depth. The soil moisture was constant at 7-10% throughout the depths from 10 to 70 cm. Judging from these results, woody plants for which the root system had grown deep in the ground and

was able to absorb water from a wide range are considered to be able to grow even in white oasis soil.

In other words, this study confirmed that the most hindering factor for the introduction of woody plants into white oasis soil is its high hardness and poor air permeability. The growth comparison test in white oasis soil under limited watering conditions confirmed that *U. pumila*, *P. persica* and *S. oblata* are adaptable to white oasis soil. The introduction of woody plants into white oasis soil under limited watering conditions is considered possible by these tree species.

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Fig. 8 Comparison of root structures, photographed on August 19, 2015, one year after the planting

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