# Afforestation Technique of *Xanthoceras sorbifolia* Bunge.

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**Abstract** We conducted the study on afforestation technique of *Xanthoceras sorbifolia* Bunge. in combination with ecological environment features of Fuxian County in Shaanxi Province. Results show that it is proper to adopt "sunny gentle slope + fish-scale pit + planting on ridges after dipping mud + stumping in autumn" for afforestation of *Xanthoceras sorbifolia* Bunge. in the Loess Plateau. It is expected that our study can play a significant role in guiding popularization of *Xanthoceras sorbifolia* Bunge. in the northwest of China.

**Key words** *Xanthoceras sorbifolia* Bunge., Afforestation technique, The Loess Plateau

*Xanthoceras sorbifolia* Bunge., also called yellowhorn, belongs to Sapindaceae. It is a rare kind of woody oil tree unique in China. As raw material of bi-diesel production, *Xanthoceras sorbifolia* Bunge. has great development potential. Besides, it is one of eight trees generating biochemical diesel oil and has the name of "Tea Oil Tree in North" [1]. In addition, *Xanthoceras sorbifolia* Bunge. also has such ecological functions as afforestation on barren mountains, water and soil conservation, windbreak and sand-fixation, as well as ornamentation. As high level woody oil tree, seeds of *Xanthoceras sorbifolia* Bunge. contain 35% to 40% oil. Oil content of kernel reaches 72%, which is more than one time of rape seed. Thus, it not only can replace part of oil crops and not occupy much arable land, but also can be used as optimum woody plant material of bio-diesel in temperate zone[2-5]. The study shows that *Jatropha curcas* Linn is the best tree in south and *Xanthoceras sorbifolia* Bunge. is the best one in north for establishing woody raw material base of bio-diesel[4]. The State Forestry Administration decided that it is planned to plant Chinese pistache and *Xanthoceras sorbifolia* Bunge. trees for respective 670 000 $hm^2$ in future years[3]. In these situations, research of afforestation technique of *Xanthoceras sorbifolia* Bunge. becomes an urgent subject in production practice of *Xanthoceras sorbifolia* Bunge. Afforestation technique of *Xanthoceras sorbifolia* Bunge. directly concerns success of afforestation of *Xanthoceras sorbifolia* Bunge. and influences development of energy forest. To reduce afforestation cost and improve survival rate and retention rate of afforestation, we observed different experimental sites for three consecutive years through arranging experimental sites for *Xanthoceras sorbifolia* Bunge. in combination with energy forest project in Fuxian County of Shaanxi Province. We studied survival rate, retention rate and growth situation of *Xanthoceras sorbifolia* Bunge. in different conditions. Finally, we concluded afforestation technique of *Xanthoceras sorbifolia* Bunge. in Yan'an City, in the hope of providing technical reference for construction and development of *Xanthoceras sorbifolia* Bunge. biomass energy forest.

## 1 General information of areas under study

Fuxian County of Shaanxi Province is located in southern part of the Loess Plateau and in middle and upper reaches of Luohe River. Its geographical coordinate is 108°29′30″ E to 109°42′54″ E and 35°44′6″ N to 36°23′23″ N. With a length of 111 km from west to east and a width of 73.7 km from north to south, Fuxian County covers an area of 4 181.57 $km^2$. Within the county, the terrain is higher in northwest and lower in southeast, and the altitude is 856.4 to 1 687 m. Ravines spread all over, and valleys and rivers are deep. The terrain in Fuxian County is complex. Fuxian County is in the middle latitude semi-arid region and has a continental monsoon climate commonly found in the temperate zone. It is temperate in climate, moderate in rainfall, rain and high temperature are in the same season, and four seasons are distinct. The average temperature of the whole year is 8.3 ℃ and the extreme maximum temperature is 38.7 ℃. Active accumulated temperature equal to or greater than 10 is 3 085.4 ℃, and frost-free period is as long as 157 days. The mean annual hours of sunshine is about 2 478.4 hours. Annual rainfall ranges from 500 to 600 mm and is mainly in July, August and September, accounting for about 60% of the precipitation of the whole year. The precipitation features short rainy season and long dry season, and rainfall is relatively concentrated. Natural disasters in Fuxian County are various and have high frequency of occurrence. Major disasters which have great influence on forestry production include frost, drought, dry-hot wind, and hail.

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## 2 Materials and methods

**2.1 Materials** The experimental sites are set in Jijia Village of Jiaodao Town, Daohuiling Village of Fucheng Town, and Yishuihe Village of Yangquan Town. Total area of experimental sites is 280 $hm^2$ (140 $hm^2$ in Jijia Village of Jiaodao Town and 106 $hm^2$ in Daohuiling Village of Fucheng Town). Saplings are supplied from one-year old high quality and strong *Xanthoceras sorbifolia* Bunge. saplings in central nursery experimental site of Fuxian County Forestry Station.

**2.2 Methods**

**2.2.1** Afforestation on different slopes: three experimental sites with an area of 667 $m^2$ are set up separately at shady and sunny slopes.

**2.2.2** Afforestation in different site conditions: in sunny slope condition, we select gentle slope and flat land and separately set up three experimental sites with an area of 667 $m^2$.

**2.2.3** Afforestation in different ways of soil preparation: in sunny slope condition, we make a comparison between influence of fish-scale pit and closed strip soil preparation on afforestation effect. We set an area of 667 $m^2$ and repeat three times.

**2.2.4** Afforestation in different seasons: in spring and autumn, we separately adopt two ways of handling saplings, namely stumping and not stumping. We set an area of 667 $m^2$ and repeat three times.

**2.2.5** Afforestation experiment with different saplings: we select one-year old saplings and two-year old saplings and separately plant them on sunny slopes and shady slopes. We set an area of 667 $m^2$ and repeat three times.

**2.2.6** Comparison between different afforestation methods: we make a comparison between effect of seedling planting, sowing, and root cutting. We set an area of 667 $m^2$ and repeat three times.

**2.2.7** Experiment of different anti-drought measures: we separately adopt dipping mud, not dipping and mulching film. We set an area of 667 $m^2$ and repeat three times.

## 3 Results and analyses

**3.1 Influence of afforestation on different slopes on survival rate, retention rate and growth situation of *Xanthoceras sorbifolia* Bunge.** From Table 1, it is known that the retention rate and annual growth of new shoot are separately up to 92.6% and 22 cm on sunny slopes, and 81.7% and 17 cm on shady slopes, because shrubs and weeds grow rapidly on shady slopes and influence ventilation and lighting of seedlings.

**Table 1 Afforestation effect on different slopes**

| Slope aspect | Survival rate//% | Retention rate//% | Growth of new shoot//cm |
|---|---|---|---|
| Sunny slope | 95.1 | 92.6 | 22 |
| Shady slope | 90.8 | 81.7 | 17 |

Table 2 shows that both retention rate and growth of new shoot on gentle slope are higher than that in flat land, mainly because *Xanthoceras sorbifolia* Bunge. is not water-logging-tolerant and flat land is easy to accumulate water and lead to root rot.

**Table 2 Effect of afforestation in different site conditions**

| Sites | Survival rate//% | Retention rate//% | Growth of new shoot//cm |
|---|---|---|---|
| Gentle slope | 94.2 | 87.3 | 19 |
| Flat land | 90.1 | 77.8 | 18 |

Therefore, to raise survival rate, retention rate and growth condition of *Xanthoceras sorbifolia* Bunge., afforestation on barren mountains should select sunny gentle slope with deep and fertile soil.

**3.2 Influence of afforestation on different ways of soil preparation on survival rate, retention rate and growth situation of *Xanthoceras sorbifolia* Bunge.** Table 3 indicates that the retention rate of *Xanthoceras sorbifolia* Bunge. is up to 92.6% in the fish-scale pit soil preparation method, while it is only 56.0% in closed strip soil preparation method. Growth of new shoot reaches 21 cm for all soil preparation methods, and the difference is not significant. The reason is that large area soil preparation leads to rapid growth of weeds, and ventilation and lighting are impaired. Besides, strip preparation method is not favorable to drainage and consequently leads to reduction of survival rate and retention rate.

**Table 3 Effect of afforestation of *Xanthoceras sorbifolia* Bunge. in different ways of soil preparation**

| Ways of soil preparation | Survival rate//% | Retention rate//% | Growth of new shoot//cm |
|---|---|---|---|
| Fish-scale pit | 95.1 | 92.6 | 22 |
| Closed strip soil preparation | 91.4 | 56.0 | 24 |

Our research also found that when seedlings are planted on ridges of outer edge of fish-scale pit, the survival rate is high. This is afforestation on ridges. Such method can prevent death of seedlings due to water accumulation in pit when flood occurs in rainy season.

Therefore, whole soil preparation method is forbidden for afforestation of *Xanthoceras sorbifolia* Bunge. It is proposed to adopt fish-scale pit and cave-shaped soil preparation methods in accordance with local actual conditions.

**3.3 Influence of afforestation in different seasons on survival rate, retention rate and growth situation of *Xanthoceras sorbifolia* Bunge.** From Table 4, we can know that the retention rate and growth of new shoot are highest on sunny slope and stumping in autumn, respectively reaches 92.6% and 22 cm, greatly higher than the way of not stumping. Afforestation in spring is slightly not good as afforestation in autumn, and influence of stumping or not in spring is not significant on afforestation effect.

Therefore, in northwestern regions where the wind is fierce in winter and it is dry in spring, *Xanthoceras sorbifolia* Bunge. can be planted in both spring and autumn, but it is preferred to plant in autumn using stumping method. In spring, it is proposed to plant *Xanthoceras sorbifolia* Bunge. during the last third of March and the beginning of April, and use the method of not stumping to speed up growth of tree. If we plant *Xanthoceras sorbifolia* Bunge. after the middle third of April, the sur-

vival rate is low. Afforestation in autumn should take place after *Xanthoceras sorbifolia* Bunge. leaves fall. To prevent drying, we may plant after stumping and keep the trunk at least 15 cm, and bury the trunk gently with soil, then it will sprout in the next spring.

**Table 4 Effect of *Xanthoceras sorbifolia* Bunge. afforestation in different seasons**

| Afforestation seasons | Stumping or not | Survival rate//% | Retention rate//% | Growth of new shoot//cm |
|---|---|---|---|---|
| Autumn | Stumping | 95.1 | 92.6 | 22 |
| | Not stumping | 75.3 | 69.5 | 17 |
| Spring | Stumping | 93.7 | 88.7 | 19 |
| | Not stumping | 93.1 | 87.4 | 17 |

**3.4 Influence of different samplings on survival rate, retention rate and growth situation of *Xanthoceras sorbifolia* Bunge.** From Table 5, it is seen that no matter shady slope or sunny slope, the retention rate of one-year old saplings of *Xanthoceras sorbifolia* Bunge. is significantly higher than that of two-year old saplings, and the growth of new shoot also has such condition. The reason is that roots of one-year old saplings are better than two-year old samplings. Fibrous root of two-year old samplings deteriorates, and main roots are thick and long, which are not favorable to afforestation on barren mountains.

**Table 5 Influence of age of seedlings on afforestation effect of *Xanthoceras sorbifolia* Bunge.**

| Slope aspect | Age of seedlings//a | Survival rate//% | Retention rate//% | Growth of new shoot//cm |
|---|---|---|---|---|
| Shady slope | 1 | 90.8 | 81.7 | 17 |
| | 2 | 80.1 | 71.3 | 19 |
| Sunny slope | 1 | 95.1 | 92.6 | 22 |
| | 2 | 75.4 | 68.9 | 24 |

In these situations, we should select optimum seedlings. It is recommended to adopt one-year old seedlings with height above 30 cm and stem longer than 0.4 cm, and free of disease and insect pest.

**3.5 Influence of different afforestation methods on survival rate, retention rate and growth situation of *Xanthoceras sorbifolia* Bunge.** Table 6 indicates that the survival rate is extremely low for afforestation by sowing, it is only 21.1% and the growth of new shoot is merely 12.8 cm. For root cutting method, the effect is slightly better, but still just 46.7% and 13.9 cm. Besides, the growth is slow and retention is not good, and main root deteriorates. Seedling method receives best effect and the retention rate is up to 92.6%. Thus, it is proposed to adopt seedling method to conduct afforestation of *Xanthoceras sorbifolia* Bunge.

**Table 6 Influence of different afforestation method on afforestation effect of *Xanthoceras sorbifolia* Bunge.**

| Methods of afforestation | Survival rate//% | Retention rate//% | Growth of new shoot//cm |
|---|---|---|---|
| Seedling | 95.1 | 92.6 | 22.0 |
| Sowing | 21.1 | 15.1 | 12.8 |
| Root cutting | 61.4 | 46.7 | 13.9 |

**3.6 Planting density of *Xanthoceras sorbifolia* Bunge. in different site conditions** Planting density of *Xanthoceras sorbifolia* Bunge. should be based on orchard type operation and management. Since site conditions are different, we compared average height and crown diameter of 5 to 10 years old and 10 to 20 years old wild *Xanthoceras sorbifolia* Bunge. in typical site condition in Fuxian County(Table 7). On ridges and sunny slopes, main tree types are shrubs. Tree height and crown diameter on ridges are greater than those on sunny slopes. For shady and steep slopes, trees are mainly arbors and the overall growth condition is worse.

**Table 7 Tree height and crown diameter of wild *Xanthoceras sorbifolia* Bunge. in different site conditions** m

| Planting density | Arbor shape | | | | Shrub shape | | | |
|---|---|---|---|---|---|---|---|---|
| | 5 to 10 years | | 10 to 20 years | | 5 to 10 years | | 10 to 20 years | |
| | Tree height | Crown diameter | Tree height | Crown diameter | Tree height | Crown diameter | Tree height | Crown diameter |
| Ridge | | | | | 2.1 | 2.6 | 2.8 | 3.6 |
| Sunny gentle slope | | | | | 1.5 | 1.6 | 2.3 | 2.7 |
| Shady steep slope | 2.1 | 1.6 | 3.8 | 3.1 | | | | |

Therefore, it is proper to plant *Xanthoceras sorbifolia* Bunge. in a more dense way on steep slopes. Generally, we plant with 2 m ×2 m space in the rows and plant 2 505 trees for one hectare land. For terraced fields or gentle slopes with better condition, it is proper to plant with 2 m ×3 m or 3 m ×3 m space in the rows and plant 1 650 to 1 110 trees for one hectare land. On soil mountains or ridges, it is proper to plant with 3 m ×4 m space in the rows and plant 840 trees for each hectare land.

**3.7 Influence of different drought-resistant and afforestation methods on survival rate, retention rate and growth situation of *Xanthoceras sorbifolia* Bunge.** From Table 8, it can be seen that the retention rate for dipping mud before planting is about 93.1%, higher than 85.4% for not dipping. The growth of new shoot for dipping mud before planting is 3 cm higher than that without dipping. Afforestation by mulching film has worse effect and the retention rate is only 67.8%.

**Table 8 Influence of drought-resisting measures on afforestation effect of *Xanthoceras sorbifolia* Bunge.**

| Drought resisting measures | Survival rate//% | Retention rate//% | Growth of new shoot//cm |
|---|---|---|---|
| Dipping mud | 95.1 | 93.1 | 22 |
| No dipping | 89.2 | 85.4 | 19 |
| Mulching film | 85.2 | 67.8 | 19 |

Afforestation by mulching film is not favorable to drainage and it is easy to get yellow mosaic, so we do not recommend using this method. Dipping mud before planting receives better effect than no dipping. However, it should be noted that mud shall be thin and dipping just before taking to mountains. It is not proper to wait for long time after dipping mud; otherwise, roots may get rotten.

## 4 Conclusions and discussions

In Yan'an City and other northwester regions that have similar climatic and geographical conditions, it is proper to adopt " sunny gentle slope + fish-scale pit + planting on ridges after dipping mud + stumping in autumn" for afforestation of *Xanthoceras sorbifolia* Bunge. On the basis of scientific and technical achievement of " Yan'an *Xanthoceras sorbifolia* Bunge. Planting Technique ", Novelty Assessment Report (No.: 201103 – 0309) issued by Sci-Tech Novelty Center of Institute of Scientific and Technical Information of Shaanxi concluded that " through comparative analysis, the *Xanthoceras sorbifolia* Bunge. Planting Technique with planting on ridges after dipping mud is unique and prospective".

**4.1 Planting on sunny gentle slopes and planting on ridges after dipping mud can solve the rotten root problem of *Xanthoceras sorbifolia* Bunge.** *Xanthoceras sorbifolia* Bunge. is not water-logging-tolerant. Its root is extremely easy to rot. When planting on sunny slopes, the survival rate is higher; seedlings planting at outer edge of fish-scale pit are better than those at inner edge, for it can avoid flood due to water accumulation in rainy season and consequently influence survival rate. In addition, planting after dipping mud is better, but it should not wait too long after dipping mud, otherwise, roots may be rotten.

**4.2 Afforestation by stumping in autumn can improve survival rate of *Xanthoceras sorbifolia* Bunge.** In northwestern regions where the wind is fierce in winter and it is dry in spring, *Xanthoceras sorbifolia* Bunge. can be planted in both spring and autumn, but it is preferred to plant by stumping in autumn. It is proposed to conduct afforestation in autumn after *Xanthoceras sorbifolia* Bunge. leaves fall. To prevent drying, we may plant after stumping and keep the trunk at least 15 cm, bury the trunk gently with soil, then it will sprout in the next spring.

**4.3 Using one-year old seedlings and local soil preparation method can obviously raise survival rate and retention rate of *Xanthoceras sorbifolia* Bunge.** It is improper to adopt whole-area soil preparation for afforestation of *Xanthoceras sorbifolia* Bunge., because large area soil preparation leads to rapid growth of weeds, and ventilation and lighting are impaired. Besides, strip preparation method is not favorable to drainage and consequently leads to reduction of survival rate and retention rate. The survival rate and retention rate for fish-scale pit and cave-shaped soil preparation are higher. One-year old saplings have higher survival rate than two-year old saplings, because fibrous root of two-year old samplings deteriorates, and main roots are thick and long, which are not favorable to afforestation on barren mountains. Sowing and root cutting methods have lower survival rate, growth is slow and retention rate is lower, while survival rate of seedling method is obviously higher.

**4.4 Planting density of *Xanthoceras sorbifolia* Bunge. should adopt methods suitable for local conditions** Planting density of *Xanthoceras sorbifolia* Bunge. should be based on orchard type operation and management. Since site conditions are different, we should plant *Xanthoceras sorbifolia* Bunge. in a more dense way on steep slopes and plant less *Xanthoceras sorbifolia* Bunge. on gentle slopes.

There are many methods for improving survival rate, retention rate and growth condition of *Xanthoceras sorbifolia* Bunge., but experiments have shown that in Yan'an City and other northwester regions that have similar climatic and geographical conditions, it is proper to adopt " sunny gentle slope + fish-scale pit + dipping mud and planting on ridge + stumping in autumn" for afforestation of *Xanthoceras sorbifolia* Bunge. This conclusion is similar to the research on relationship between cluster intensity and site conditions of natural *Xanthoceras sorbifolia* Bunge. in the Loess Plateau[5-6].

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