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# SUPERIOR BROAD-LEAVED SPECIES *ALNUS CREMASTOGYNE*, ITS HABITAT, LIFE HISTORY, SPECIAL USES AND GENETICS

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*Alnus cremastogyne* is a Chinese endemic species of *Alnus* in Betulaceae family and is a very important commercial tree species in the subtropical regions of China. Many works on its distribution and characteristics have been carried out in China. However, a comprehensive and systematic review on *A. cremastogyne* is still needed for the seeds and the cultivation methodology, where it holds the key research directions in the future, for the natural forest protection and its plantation cultivation. The current work involved systematically review on its progress in the habitat, life history, special uses and genetics. The work also comprehensively described the silviculture element, which is beneficial to the understanding, evaluation, protection and utilisation of *A. cremastogyne*.

Keywords: *Alnus cremastogyne*, habitat, life history

## INTRODUCTION

*Alnus cremastogyne* is a Chinese endemic species of *Alnus* from the Betulaceae family. This tree is a very important commercial species in the subtropical regions of China (Zhou 2007, He 2008). *Alnus cremastogyne* has developed shallow roots as an adaptation to flooded habitats, rapid growing pace to warm climates of the subtropical regions and high fruit yields in natural regeneration forest (He 2008, Zhou et al. 2018). Normally, the trunks are upright and the roots have rhizobia. The leaves are an important food source for wild animals or fauna of subtropical China (Yang et al. 2008, Zhang 2012, Zou et al. 1998). Its timber functions as pulpwood or be processed into plywood (Liu 2007, Ren et al. 2016). Many works for its distribution and characteristics have been done in China. However, we still need a comprehensive and systematic review on *A. cremastogyne*. Therefore, we systematically reviewed the progress in the silviculture research on its habitat, life history, special uses and genetics; which is beneficial to the understanding, evaluation, protection and utilisation of *A. cremastogyne* in the future.

## Habitat

### *Native range*

The native range of *A. cremastogyne* includes Sichuan province, northern Guizhou province, southern Shanxi province, southeastern Gansu province and northeast Yunnan province, while Chengdu Basin being the center of its native range (Zhou 2007, Ge 1985). Since the 1960s, it has been successfully introduced and cultivated in Hunan province, Hubei province, Anhui province and Jiangxi province (He 2008). Nowadays, the distribution ranges from Kangding (102° E) of Sichuan province to Zhoushan (121°49' E) of Zhejiang province and from northeast Yunnan (26° N) to the south slope of Qinling Mountain (33° N). *Alnus cremastogyne* can grow in the areas where the Yangtze River flows, but the optimum area is Qionglai mountain in Sichuan province (Yang et al. 1995, Zhou 2007, Wang 2000).

### *Climate*

*Alnus cremastogyne* grows under specific climatic conditions that are mostly tropical monsoon climate where the temperature is favorable and the precipitation is abundant. Mean annual temperature ranges from 15 to 18 °C. The extreme low temperature is -14 °C. Annual precipitation ranges from 900 to 1400 mm (Tian et al. 2013, Wang 2008). Qionglai mountain in Sichuan province is the optimum area for *A. cremastogyne* growth, which is located at the edge of Sichuan Basin and has alpine climate characteristics, with a mean annual temperature of 16.3°C, annual precipitation of 1117.3 mm and frost-free period of 285 days. Longquan mountain in Sichuan province is also a suitable area for *A. cremastogyne,* although its annual evaporation is 1500 mm and is notably greater than its annual precipitation of 960 mm (Yang 1991).

*Soils and topography*

*Alnus cremastogyne* grows on a wide range of soils and topographies. It is found on seashore bottomlands, valleys, plains and hilly lands. *A. cremastogyne* grows on various soil types including marine argillaceous sandy soils, gravelly soils, sandy loam soils, red yellow soils, latosol soils and purple soils; on a wide range of soils thickness from 40 to 200 cm; on a wide range of pH values from 4.4 to 8.6 and on soils of diverse nutrient conditions of organic matter contents from 0.709 to 8.562 %, total nitrogen contents from 0.050- to 0.278-%, and phosphorus contents from 0.046 to 0.172 % (Yang 1991). It is found that sandy loam soils of both sides of rivers and loam soils of hilly lands are conducive to its growth (Yang et al. 2008, Lin 2015, Huang & Lai 2014).

Although the native range of *A. cremastogyne* seems narrow compared with other widespread species in China, the topography and geomorphology in its original areas change greatly, most notably the altitude variation in the eastern edge of the Sichuan-Tibet Plateau. Therefore, the altitude range of its native distribution is from 500 to 3000 m and the cultivated area of it is from 5 to 3000 m (Wang 2008, Chen et al. 1999). The major site factors influencing *A. cremastogyne* growth are slope shape, position on slope and altitude. The survival rate and growth rate of *A. cremastogyne* on intermediate inclination and bottom inclination are significantly higher than that on upper inclination (Lian 2005, Zhuo 2003, Wang et al. 2005, Wen et al. 2012). The influences on its growth rate resulted from altitude variation are dominant, longitude variation secondary and latitude variation not obvious (Zhuo 2003, He & Chen 2002). Valley sites are more favorable for its growth than hillside sites (Deng 1981). However, sites of windward ridges, windward slope and slope gradient >20° are not conducive to the growth of it.

*Associated forest cover*

*Alnus cremastogyne* grows in association with many other trees, the most important of which are Chinese fir *(Cunninghamia lanceolata)*, cedar *(Cupressus funebris)*, masson pine *(Pinus massoniana)*, machilus *(Phoebe zhennan)*, Japanese cedar *(Cryptomeria fortunei)*, Thorn Chinese catalpa *(Kalopanax septemlobus)*, camphor *(Cinnamomum camphora)* and liriodendron *(Liriodendron chinense)* (Wang 2008; Xu et al. 2008). The most frequent associates are Chinese fir and cedar.

## Life history

*Reproduction and early growth*
*Flowering and fruiting*

*Alnus cremastogyne* is a deciduous tree burgeoning forth from late February to early March in spring depending upon altitude. Its new shoots start growing in mid-March, and its leaves fall in late autumn and early winter every year (Figure 1 & Figure 2). It flowers in the spring at about the same time when its leaves appear. It is monoecious, i.e., flowers of both sexes are present on the same individual. The staminate flowers are in 3 to 4 cm catkins. In May, infructescence is formed, which is oblong with 1 to 3.5 cm in length and 5 to 20 mm in diameter (Tang 2015). Seed maturity is reached in approximately 250 days after pollination (Figure 3). Physiological maturity, as indicated by normal germination is reached when the colors of infructescences change from green to dark brown in November or December depending upon altitude (Figure 4). Seeds germinate shortly after falling to the ground in November or December. At maturity, the average weight of an infructescence is 1.62 g. The gross seed yield from an infructescence is 5.56%, the pure seed yield from an infructescence is 3.76% and the gross seed contains waxy powder (Yang et al. 1989, State Forestry Bureau of China 2010,

**Figure 1** The natural forest stand state of the growing season of *Alnus cremastogyne*

**Figure 2** The natural forest stand state of the dormant season of *Alnus cremastogynea*

**Figure 3** The extra small seeds of *Alnus cremastogyne*

**Figure 4** The unique infructescences of *Alnus cremastogyne*

State Forestry Bureau of China 2019). The weight of an infructescence is negatively correlated with the seed yield and the thousand seeds weight. Seeds are small nuts, ovate and about 3 mm long (Tang 2015).

*Seed production and dissemination*

In general, *A. cremastogyne* has a short young forest period and five-year-old trees can blossom and bear seeds, and the full bearing period starts after 10 years. Normally *A. cremastogyne* seed production does not vary annually, but it varies among individuals within a given year and much of the variation in seed production can be related to flower abundance at the time of pollination (Xi 2003). There is a significant positive correlation between infructescence production and average temperature in March during the *A. cremastogyne* pollination period. There is a significant positive correlation between infructescence production and the number of sunny days because open pollination is directly related to the weather. Generally, from mid-November to early January of the following year, bracts of infructescence dehisce and seeds fall under the influence of the wind. Spontaneously-shedding seeds of *A. cremastogyne* have no dormancy characteristics (Yang et al. 1989). Seedlings via natural regeneration can be seen in about eight-year-old stands of *A. cremastogyne*.

*Germination and seedling development*

Germination is epigeal and mature *A. cremastogyne* seeds have a germination capacity between 17.5 and 30.0%, and produces thousands of seeds weighing between 0.345 and 0.681 g. Seeds germinate in the fall soon after dropping, requiring no pretreatment for germination. The germination capacity of seeds is greatly affected by the age of the seed tree, the altitude range of the seed tree distribution, and the slope direction of the seed tree distribution. For example, the germination rate of seeds is high when the seed tree is young (5–10 years old), distributed at low altitude (below 800 meter), and distributed at east or southeast slopes (Yang et al. 1989). The seeds are very small and are comparatively weak to sprout; thus the thickness of the leaf litter can affect the germination of the seeds. Seedlings are small (Figure 5); therefore, they are not competitive. They are susceptible to full sunlight, drought, weeds, diseases and insect pests (Liu 2012). About 20 days after sowing in mid-March, *A. cremastogyne* seedlings emerge from the soil. After the emergence of the seedlings, the aerial parts of seedlings grow slowly, normally at 3 to

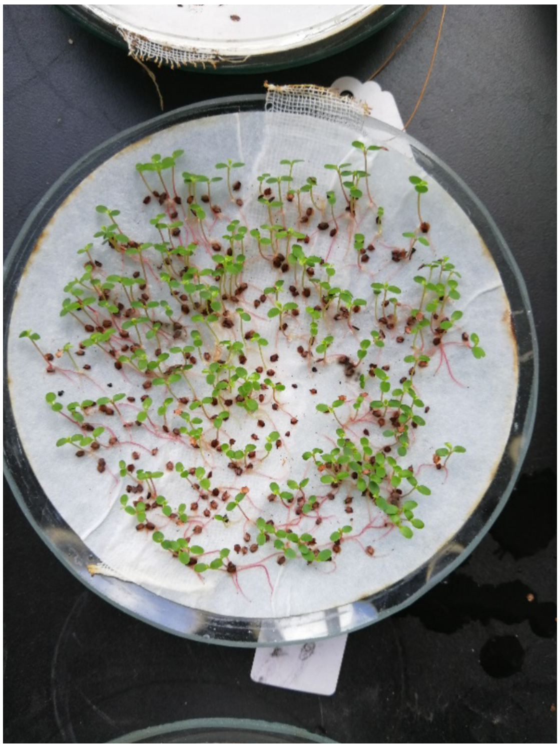

**Figure 5** The seedlings of *Alnus cremastogyne*

4 cm in height when the age of the seedlings is about 50 days and less than 10 cm in height when the age of seedlings is 75 days. When the sixth pair of true leaves has developed in June, the growth of the aerial parts of the seedlings significantly accelerates and the root nodules begin to form. The rapid growth period of seedling height begins in July, the peak of seedling height growth rate is in September, and the growth rate of seedling height decrease significantly in October. The growth of the seedlings approximately stops in November (Zou et al. 1998, Xi 2003, He & Chen 2002, Huang & Lai 2014). For one-year-old seedlings, the seedling height is from 47.1 to 72.5 cm, and the stem diameter is from 0.7 to 1.5 cm. For two-year-old seedlings, the period of logarithmic growth of seedling height starts from April, the period of linear growth of that begins in May, the growth of that approximately stops in November, and the defoliation is in December.

*Vegetative reproduction*

Small *A. cremastogyne* trees sprout prolifically and vigorously when cut or damaged by fire (Xu et al. 2008). The ability to sprout depends on the age and genetic characteristics of the parent trees. Sufficient nitrogen content in soils can significantly promote the growth of sprouts, specifically the length and number of sprouts. When compared with the low stumps (about 30 cm), the high stumps (about 90 cm) produces more sprouts. The number and length of sprouts can be increased via pruning the parent tree and the pruning intensity by a light cut is considered optimum (Qi 2007, Wu et al. 2006, Yang et al. 2005).

For the cuttings cultivation of *A. cremastogyne*, the younger the parent trees are, the higher the rooting rate of cuttings will be. The rooting rate of the cuttings can be significantly increased while the top bud or a leaf is retained. The optimum time of cutting is from mid-May to mid-June (Zhou & Wu 2004).

*Sapling and pole stages to maturity*
*Growth and yield*

*Alnus cremastogyne* is a large, long-lived tree often 30 to 40 m in height and 20 to 40 cm in dbh (diameter at breast height) (Yang et al. 2008). Individual trees at 40 m high with 150 cm in dbh has been recorded (Wang 2012). In the open environment, it is characterised by a short stocky bole with a wide and rugged spreading crown. In the forest, *A. cremastogyne* develops a tall, straight trunk with a compact crown. Its annual growth period is ten to eleven months because of early foliation in spring and late defoliation in winter. It shows great productivity in its early ages. In Mianyang city of Sichuan province, one-year-old individuals at 1.80 ± 0.20 m high and 1.10 ± 0.13 cm in dbh; two-year-old individuals at 3.20 ± 0.26 m high and 2.60 ± 0.21 cm in dbh; three-year-old individuals at 5.10 ± 0.48 m high and 4.70 ± 0.45 cm in dbh and four-year-old individuals at 6.20 ± 0.50 m high and 6.40 ± 0.52 cm in dbh have been recorded, respectively (Ren et al. 2016). In the natural native range of *A. cremastogyne*, five-year-old individuals at 9.8–11.5 m high, 7.94–10.85 cm in dbh and 22.77–33.42 kg in biomass have been documented (Yang et al. 2008). In Yueyang city of Hunan province, nine-year-old individuals with 44.39 kg in biomass have been obtained. The annual increments of height, diameter and volume all recorded decrease when it is eight to ten years old. Thirteen-year-old individuals at 13.5–19.8 m high and 12.9–17.5 cm in dbh have been recorded (Xu et al. 2006). The period of vigorous growth of height and dbh are from five to fifteen years (Wang 2008). In a particular year, the peak growth period of *A. cremastogyne* is from May to August, the peak period of stem base diameter or dbh growth is in May, and the peak period of height growth is in July. When individual trees are two to twelve years old, the average net productions of its structures all increase and then decrease by certain percentage from fourteen years old. Ultimately the individual trees become mature when they are sixteen years old (He 2008). *Alnus cremastogyne* is a fast-growing tree cultivated for paper production, plywood production and timber. The optimum final felling age is at eight to ten years old when cultivated for paper, ten to thirteen years old for plywood, and eighteen to twenty years old for large-diameter timber (Huang & Lai 2014). The thickness of soils and the age of the forests have significant influences on standing stock and stocking volume per unit area. The height of its growth is significantly correlated with precipitation, accumulated temperature and soil organic matter content.

## Rooting habit

*Alnus cremastogyne* is shallow-rooted which is a trait that persists from its young to maturity stage.

The lateral roots are highly developed while the taproots are not obvious. Its root system is a forked branch structure between the scattered root type and the horizontal root type. The horizontal distribution radius of the root system is 2.29 times as large as its vertical distribution root depth. Its root system is mainly distributed in 0 to 40 cm soils, which accounts for 96.14% of the total root system (Niu et al. 2020, Li et al. 2006, Li 2010). When individual trees are seven years old, the biomass density of its rootlets is 0.156 ± 0.030 kg $m^{-3}$, the rootlets surface area density is 0.99 $m^2$ $m^{-3}$ and the rootlets length density is 110.33 m $m^{-3}$ (Chen et al. 2020). When individual trees are eighteen years old, their root width can reach 6 m × 6 m, and root system distributed in 0 to 20 cm soils accounts for 77.73% of the total root system (Li 2010). The root system can increase the absorption of nutrients in soils via the strategy of expanding the root distribution by adding secondary roots (Chen et al. 2020, Cai et al. 2010).

## Reaction to competition

*Alnus cremastogyne* is generally regarded as less tolerant to shade and drought, but has higher tolerance to water. For example, a stand of *A. cremastogyne* in Lutou forest farm of Pingjiang county grows very well in soils with water accumulation for three months in one year. On the contrary, in the sites with shallow soils and poor nutrition, *A. cremastogyne* grows poorly or even does not survive. When it is seven years old, its average height is 13.5 m, average dbh is at 12.6 cm and the average volume 0.08141 $m^3$; while the height of a superior tree is 18.5 m, the dbh is at 22.4 cm with the volume of 0.32001 $m^3$. Its aerial parts growth is significantly affected by high temperature and drought, and saplings are often killed when the environmental stress occurs. In a stand of *A. cremastogyne* in Caobai forest farm of the You county, 80 percent of the individuals died because of drought (Xu et al. 2006). Saplings that are more than four years old are more resistant to drought than those that are less than three years old (Wu 1992).

Due to its rapid growth, especially the growth in its height during the early stage, the tree becomes too thin and too high, and produces weak wood structure. Thus, a high proportion of 20% to 25% of the trees are bent by the wind and snow stress, and occasionally results in broken and damages tops or trunks (Xu et al. 2006).

*Alnus cremastogyne* responds well to intermediate cutting. At the stage of seedlings and saplings of about three years old, two times of the intermediate cutting have been done from May to June and from August to September every year. The methods of intermediate cutting include removing shrubs and weeds in forest land and loosening the soils within a radius of 80 cm centered at individual trees (Xia & Yu 2000, Xu et al. 2000). When individual trees are six to seven years old, the intermediate cutting has been done according to the growth conditions of *A. cremastogyne.* Shrubs and weeds in forest land are removed, and some trees are labeled and felled on the principle of "three types cut and three types retained", which means to cut the stunted trees and retain the tall ones, to cut the ones with bad trunk shapes and to retain the ones with good trunk shapes and to cut the densely distributed ones and to retain the sparsely distributed ones (Xu et al. 2000). When *A. cremastogyne* is cultivated as short-cycle industrial raw material forest, the optimum final felling age is nine to ten years old and the wood can be harvested 225 $m^3$ $hm^{-2}$. When cultivated as large-diameter timber, the second intermediate cutting is done at the age of ten, the optimum final felling age is fourteen years old, and wood can be harvested more than 300 $m^3$ $hm^{-2}$ (Xu et al. 2000).

## Damaging agents

The pests and diseases of *A. cremastogyne* are rare in the seedlings stage and young forest. Except for sooty mold and thorn moth which may occur locally, other pests and diseases in forest need not be controlled which greatly reducing the management cost. The threatening diseases are stem rot, sooty mold and sunburn. The perilous pests are cutworms, mole crickets, leaf beetles, blue chafers, termites, and thorn moths (Liu 2012, Xi 2003).

Stem rot mainly harms the stem base, the taproot and lateral roots. At first, the site of disease is on stem appearing in dark brown and then extends to the stem base. Subsequently, the leaves turn yellow and wilt occurs. Eventually, the seedling dies. The sooty mold infects the leaves and branches of *A. cremastogyne,* which decreases the photosynthetic rate of its leaves and seriously inhibits the growth of it.

Sunburn injury occurs mainly at the root collar of seedlings. Because the seedlings are so tender, the root collar then thins and shrinks due to the excessive surface temperature. Ultimately, the seedling dies. The cutworms damage mainly occurs in May and July. At night, cutworms eat the young leaves and chew off the tender stem. From seedlings emergence to the formation of 6–8 true leaves, seedlings are easily harmed by mole crickets. Mole crickets chew off the tender stem and causing the seedling to die. Blue chafer is a perilous pest for seedlings, young forest and mature forest. Its larvae eat young leaves and chew off seedling roots, while its adults also consume mature leaves.

## Special uses

*Alnus cremastogyne* is a non-leguminous, nitrogen-fixing tree species with root system rich in nodules. This tree species can improve soil and is considered an important tree species for forestation and has indispensable ecological functions. *Alnus cremastogyne* is highly adaptable It has a short juvenile period, high seed yield and rapid growth rate. Thus, it has become a crucial tree species in the Returning Farmland to Forest Program, ecological reconstruction programs and mixed-species forest plantation in the Yangtze River valley in China (Xu et al. 2008, Guo et al. 2019).

*Alnus cremastogyne* timber can be utilised as plywood, pulpwood, musical instruments and furniture because of its characteristics including moderate hardness, absence of knots and had 1.02 mm fiber length. Its bark and epicarp can be used to make dyes and produce tannin extracts due to its high tannin content. Its charcoal can be used to make gunpowder. Its leaves can be used as green fertilisers and green feeds. Its pollen is the essential ingredient for bees to manufacture honey. Its sawdust is the chief material for mushroom substrates. *Alnus cremastogyne* is an excellent fuelwood tree species as it is fast-growing and coppice readily (Xu et al. 2008, Yang et al. 2013).

*Alnus cremastogyne* is also an excellent ornamental tree species with its tall trunk, wide crown, beautiful leaf shapes and hues, large and beautiful inflorescence and dense foliage.

## Genetics

The *Alnus* species belongs to Betulaceae family of which there are more than 40 species, 11 among which are in China (Rao et al. 2016). The species of Alnus is further divided into four groups: Sect. Clethropsis, Sect. Alnus, Sect. Cremastogyne, and Sect. Alnobetula (Zhuo 2003). There are three species in Sect. Cremastogyne: *A. cremastogyne*, *A. ferdinandi-coburgii* and *A. lanata*, all of which are endemic to China. *Alnus cremastogyne* is the most important species in Sect. Cremastogyne, which is found naturally in northern Guizhou province, Sichuan province, southern Shanxi province and southeast Gansu province. *Alnus cremastogyne* is replaced naturally by *A. ferdinandi-coburgii* in southwest Sichuan province, west Guizhou province and Yunnan province. The southern limit of the distribution of *A. ferdinandi-coburgii* is at 23° N. *Alnus ferdinandi-coburgii* is naturally distributed in moist mountainous regions from 1500 to 3000 m above sea level. *Alnus lanata* is only found naturally in western Sichuan province (Zhuo 2003).

For *A. cremastogyne*, both the interpopulation variations and the individual variations within a population are abundant and the individual variations within a population is significantly greater than the interpopulation variation on the traits of wood density and fruit morphology (Chen et al. 1999). The differences of growth characteristics, which are tree height, dbh and volume between provenances are very significant but those between families are not as significant (Wang 2000). The variations of its growth traits are greater than those of its timber traits, and there is no significant correlation between the traits, and thus each trait can be improved independently (Xu et al. 2006). The results of RAPD markers indicate that the genetic differentiation of the populations is low. The genetic variation is 10.16% between populations, while the genetic variation is 89.84% between individuals within a population. Therefore, the selection of excellent individual trees is more important than that of populations (Zhuo 2003, Zhuo & Chen 2005). The research on population genetic variations in *Alnus cremastogyne* with simple sequence repeat markers was investigated, showing that *A. cremastogyne* has a relatively high level of genetic diversity. Furthermore, 97% of the variation existed within populations, while only 3% was among populations, and the geographical distribution of *A. cremastogyne* was significantly correlated with elevation (Guo et al. 2019). Its karyotype is 2B (Yang et al. 2013, Ren & Liu 2006).

## Prospection

*Alnus cremastogyne* has great economic and ecological significance because of its fast growth boosted by the root nodules and its improvements to the soil via defoliation. Thus, the natural forest protection and plantation cultivation of this tree species appear noteworthy.

Improving the seeds and the cultivation methodology were the key to the natural forest protection and plantation cultivation of *A. cremastogyne*. The collection and preservation of germplasm resources are the foundation in the improved seeds breeding; therefore, the construction of a germplasm bank and core collection is one of the key directions for future research on *A. cremastogyne*. As a basis for the construction of a germplasm bank and core collection, the genetic diversity of this species should be explored continuously. The establishment of the optimal cultivation methods such as site selection, land preparation for afforestation, afforestation methods, afforestation density, arrangement of the loci of individuals, soil moisture management, soil nutrient management, woodland leaf litter management, stand density management and pruning of trees matching combine with the improved seeds is another key direction for future research on *A. cremastogyne*. Previous example of scientific work on the standardisation of plantation techniques (e.g. tree spacing, pit size, and irrigation) was done on *Dalbergia latifolia*, *Terminalia arjuna*, *Terminalia bellirica* and *Gmelina arborea* by Mohammad et al. (2021). As a conclusion, the continuous and intensive researches on *A. cremastogyne* would promote the utilisation of this tree species in the forest project and the national afforestation project in China.

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