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Present Situation of Eucalypts Breeding and Future Prospect in China

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Abstract

Breeding is the major procedure in forest research. The basic goal in all of breeding program is to expand the frequency of favorable alleles or the frequency of specific combinations of favorable alleles in the breeding populations through recurrent selection in order to improve the performance of individual plants. During the past three decades, an increase in research on breeding has improved *Eucalyptus* productivity, and to some extent our standing of their effects on tree growth and on wood properties. Unfortunately, very little information about breeding on the review of *Eucalyptus* grown in China has been published even though this species was introduced some 120 years ago. This paper reviews the available information regarding research status and prospect of breeding under Chinese ecological conditions and to outline some suggestions to them. According to the present research situation of breeding, we would recommend that: generalizing empirical and useful practices; developing high-value products; creating more clones for demand; carrying out intensively research over different species and clones for different cultivation goals at different sites over time; above all, applying breeding strategy, especially for multiple generations and interspecific hybrid breeding.

Keywords: Eucalyptus; Breeding; Research progress; Strategies

1 INTRODUCTION

The launching of large-scale plantation programs did not begin in many tropical and subtropical countries until 1960s and there was a significant increase in the area of plantations for industrial purpose by 2000 (Bull 2006). As the global population grows and areas of native forest decreases and the protection of natural forests by governments, particularly in developing countries, there are increasing demands for pulp and paper and wood products from tree plantations and agroforestry (Xu and Dell 2002; Huang and Dell 2002; Danusevicius and Lindgren 2002;Kien *et al.* 2009).Forest trees, unlike livestock or crops, have a long life span and take a long time to be replaced and the expression of genes in relation to age and competitive environment is likely one of the most important features to consider in tree genetics and tree breeding (Kusnandar *et al.* 1998; Borralho 2002; Bouvet *et al.* 2003). However, short-rotation plantation management has been becoming a more and more important forest practice in many countries, particularly those lacking land or forest resources and with pressures from increasing populations and demands on forest products (Wei 2002).

Most of eucalypt species are naturally distributed in the continental Australia of Oceania, and a few native to the Timor Island of Indonesia and Papua New Guinea (Qi 2007). Eucalypt has many characteristics that make it suitable for plantation forestry when compare to other forest species, such as fast-growing, well adaptability, short-rotation, excellent wood properties, vigorous hybrids and large natural genetic populations occur (Xu and Dell 2002; Huang and Dell 2002; Danusevicius and Lindgren 2002; Martin 2002; Kien *et al.* 2009; Warren *et al.* 2009). However, younger, fast-grown *Eucalyptus* logs possess a wide range of inherent defects representing barriers to their easy, efficient and low-cost conversion to lumber and rotary veneer because of spiral grain, growth stresses, knots, abnormal shrinkage, saturated moisture content and brittle heart (Shield 2002).

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For the last thirty years, the eucalypt plantations have experienced an important development in the subtropical and tropical zones (Martin 2002), and considerable successful improvements also have been achieved by genetic breeding in China. Varghese *et al.* (2008) evaluated 188 open-pollinated families of *Eucalyptus camaldulensis* Dehnh from 18 Australian natural provenances and 15 selected Indian families in three provenance-family trials at contrasting sites in southern Indian. Borralho (2002) summarized that breeders and foresters in general must work together and find the right balance between the various opportunities to improve the value of eucalypt plantations.

A lot of work on breeding of *Eucalyptus* in China has been published since this species was introduced some 120 years ago. This paper reviews the available information regarding breeding under Chinese ecological conditions and to outline some suggestions to them.

2 PRESENT SITUATION ON BREEDING

According to the seventh forest assessment, China's forest covers 195 million hectares, about 20.36 percent of the land area. However, demand for paper has grown considerably over the past decade, in line with China's growing economy, and this trend is forecast to continue (Bueren 2004). Because of the global warming and timber supply deficit, the Chinese Ministry of Forestry has been to increase 40 million hectares forest area and 1.3 billion m^3 forest growing stock in 2020 compared to 2005. Strategies for achieving this goal in short rotation plantation systems include genetic tree improvement, extend plantation area as well as improved harvesting practices, such as selection and breeding, convert cultivated land into forests and vegetation management treatments (Toit *et al.* 2010). Among the genera selected for plantations, eucalypt seems to be a suitable tree species to make an important contribution to wood production on a long-term sustainable basis in southern China, where the climate is conductive to high growth rates (McKenney 1998). Eucalypt plantations now cover an estimated area of more than 4.0 million hectares (Chen and Chen 2013), principally in Guangdong, Guangxi, Hainan Island, Yunnan, Sichuan and Fujian provinces while more than 1.4 million hectares in Guangxi (Liley 2014).

Unfortunately, most of China's eucalypt plantations are established with germplasm derived wholly from *E. grandis* W. Hill ex maiden, *E. urophylla* S. T.Blake or from hybrids of this two species (Hardy *et al.* 2002; Bueren 2004; Luo *et al.* 2010). Eucalypt plantations are harvested for veneer, pulpwood, artificial fiberboard, sawlogs, roundwood, fuel wood and soil (Arnold *et al.* 2013). In the tropical and subtropical regions of the other parts of the world, the mean annual yield of eucalypt plantations is more than 20 m^3 ha^{-1} $year^{-1}$, and some commercial plantations in countries such as Brazil, south Africa, Congo and Australia can be as much as 30-90 m^3 ha^{-1} $year^{-1}$ (Mo *et al.* 2002; Toit *et al.* 2010). In Contrast the mean annual increment in volume of eucalypt plantations in China is lower than that and also very variable from 2 to 70 m^3 ha^{-1} $year^{-1}$, which suggesting great potential for improving productivity of eucalypt plantations in southern China (yang 2003; Xu 2003). Increasing the productivity of existing plantations is thus necessary to supply the growing consumption of wood and fiber in the country and it offers the largest potential for reducing the unit cost of wood production (Toit *et al.* 2010). Reasons of poor performance include lack of genetically-improved planting material, generally degraded soil, especially phosphorus deficient (Xu *et al.* 2002), poor quality of clones and nonstandard afforestation (Mo *et al.* 2002). Some of these reasons also exist in Vietnam (Hai *et al.* 2008a; Hai *et al.* 2008b; Kien *et al.* 2009), Indian (Varghese *et al.* 2008) and South African (Toit *et al.* 2010).

Eucalyptus as an exotic species has a long history (Wang *et al.* 1999; Martin 2002). Systematic *Eucalyptus* breeding efforts started in the late 60's in Portugal (Borralho 2002). It is now being studied comprehensive and developed extensively in many countries around the world and constitutes one of the most researched and bred forest species (Borralho 2002). According to the different breeding material, Lu (2009) summarized three steps on selection and breeding in China. They are natural hybrids step (1960s to 1970s), artificial hybrids step (1970s to 1980s) and high speed development step (1980s to present). Bueren (2004) concluded that the genetic improvement of trees through selection and breeding should involve three processes of scientifically controlled trials, namely, the introduction of new germplasm and the establishment of field trials at different locations, select best-performing trees from the trial sites and establish seed orchards for commercial seed or for breeding, and further research on program of controlled breeding.

2.1 Specie/Provenance/Family Testing

It is believed that species selection is the first factor to consider and need to be closely matched to site conditions. At least half the rotation length should be spent on species trials, and there may be a substantial time delay if suitable trials exist or a species is already being widely used (Mead 2005). Eucalypts were first introduced into China by unselected and often incorrectly named in about 1890 and originally planted as ornamentals and roadside shade trees (McKenney 1998; Qi 2002; Bai *et al.* 2003; Bueren 2004; Qi 2007). Large-scale areas of plantations were established by state forest farms for the purpose of protecting water and soil conservation and supplying sleepers, timber and fuel wood by 1950s (McKenney 1998; Qi 2002; Bai *et al.* 2003; Bueren 2004). Government-sponsored planting programs during 1970s and 1980s increased the plantation estate to about 600 000 ha for wood chips and pulps, which mainly established by state-own forest farms and companies (Qi 2002; Bueren 2004). The productivity was low (5 to 8 m^3 ha^{-1} $year^{-1}$) and had relatively poor pulping properties because trees from unimproved genetics stock were planted on infertile soils with little or no fertilizer (McKenney 1998; Bueren 2004). It was not until the 1990s that private sector and farmers mainly developed eucalypt plantations (Qi 2002). After 20 years of breeding and silviculture, newly established commercial plantations have been substantially improved to more than 20 m^3 ha^{-1} $year^{-1}$ (Mo *et al.* 2002; Bueren 2004). The species successfully introduced and widely planted in the earlier times included *E. exserta* F. Muell, *E. globulus* Labill. ssp. Globules, *E. citriodora* Hook, *E. robusta* Sm., *E. camaldulensis* Dehnh., *E. tereticornis* Sm. and so on.

Although more than 300 eucalypt species have been introduced to China, only about 200 have survived and of these only about 15 species are of importance for commercial plantations (Simpson *et al.* 2002). Lin *et al.* (2003) analyzed five trials established in Hunan and concluded that provenances of *E. dunnii* Maiden, *E. saligna* Sm., *E. camaldulensis*, *E. benthamii* Maiden & Cambage and *E. tereticornis* have potential for plantation in some Hunan environments. Based on the introduction experience in Sichuan, Li and Hu (2003) summarized three conclusions. Primarily, Eucalypts which from high altitudes in the northeast of Australia and Indonesia, and elsewhere in the summer-rain area of eastern Australia, can grow successful in the Sichuan basin, e.g. *E. grandis*, *E. dunni*i, *E. salign*a, *Corymbia maculata* K.D. Hill & L. A. S. Johnson , *E. robusta* Sm. and *E. urophylla* (Indonesia). Secondly, eucalypts from high latitude, winter-rainfall areas or dry areas, such as E. *globulus* and E. *nitens* Maiden, can be introduced in hilly areas with a subtropical, cool climate in southwest Sichuan, whereas not in the Sichuan basin. Furthermore, eucalypts from uniform rainfall areas in the mid-latitudes of eastern Australia, includes *E. maidenii* F. Muell., *E. youmanii* Blakely & Mckie and *E. smithii* R.T. Baker, may grow well in the subtropical cool climatic area and above 600 m in Sichuan basin.

It is well known that family selection within provenances is a major strategy to increase productivity. Research Institute of Tropical Forestry (RITF) has made great contribution to provenance/family testing such as *E. urophylla* (Liang and Bai 2003), *E. wetarensis* L. D. Pryor (Lu *et al.* 2004), *E. tereticornis* (Xu *et al.* 2003; Lu *et al.* 2003) and *E. camaldulensis* (Lu *et al.* 2000). After analyzing the survival and growth characteristics of 53 provenances within 21 cold-tolerant species of *Eucalyptus*, Liu *et al.* (2009) found that the original altitude had little effect on growth and adaptability, whereas rainfall pattern was the key factor for introduction. Xu *et al.* (2003) compared the growth of 100 families within 14 provenances of E. *tereticornis* and suggested that more provenances should be introduced from Queensland in order to enrich genetic resource and make foundation for genetic breeding in future.

2.2 Tree Breeding

The basic goal in all of breeding program is to improve the performance of individual plants by increasing the frequency of favorable alleles or the frequency of specific combinations of favorable alleles in the breeding populations through recurrent selection. Beyond the traditional recurrent way for genetic improvement of the pure species, eucalypts enter quickly to produce commercially interesting interspecific hybrids by natural or artificial reciprocal recurrent way because Eucalyptus genus is very polyspecific, and its species are genetically close and are frequently crossable (Martin 2002; Borralho 2003). Therefore, the interspecific hybrids can give very rapid gains, some of which are even impossible to obtain by selection within the pure species (Martin 2002), for example, eucalypt hybrids are today the basis for most plantations in Brazil, southern African, Congo and China, and new hybrids are being developed to broaden this initial generation of crossbreeding (Borralho 2003).

During the 1990s, the Chinese began a program of hybrid breeding with the support of the Australia Center for International Agricultural Research (ACIAR) (Bueren 2004). In the early 1990s, most of the breeding effort was concentrated on tropical and subtropical species of eucalypts, e.g. Guangdong and Hainan Island, and it was not until 1999 that cold tolerant species received specific attention in Yunnan, Guangxi, Hunan and Fujian (Bueren 2004; Lu 2009). The main species widely used in commercial plantings, such as *E. urophylla* × *E. grandis*, were introduced and selected during this time. RITF has made 1760 intraspecific and interspecific combinations using *E. urophylla*, *E. grandis*, *E. terticornis* and *E.camaldulensis* and established 270 hybrid progenies in 25 experiments in Guangdong, Hainan Island, Jiangxi and Fujian provinces (Bai *et al.* 2003). The Dongmen State Forest Farm, China Eucalypt Research Center, Guangxi Academy of Forestry Research and other research institutions also achieved much work in that time (Bai *et al.* 2003; Lu 2009).

We have achieved great performance in 1990s, but fewer clones were selected in the past decades (Lu 2009; Pegg *et al.* 2006). The main reasons may be due to simple breeding strategy, lack of long-term and stable research program, simple mating design, lack of genetically-improved planting material and simple breeding goal. Therefore much work need to be done as follows: Firstly, we should intensively utilize the existing genetic sources and introduce more genetic sources from Australia and Indonesia in order to improve breeding material and make basis for accomplishing stable research program and multiple-generation breeding (Xu *et al.* 2001; Wu *et al.* 2001). Secondly, more mating designs need to be used for breeding, such as polycross, factorial tester, complete diallel and partial diallel rather than open- or wind-pollinated and simple design. There are relatively few published studies on *E. maidenii* (Li *et al.* 2003a), *E. globules* (Li *et al.* 2003b), *E. urophylla*, *E. camaldulensis*, *E. grandis* and *E. pellita* (Lu 2009; Wu *et al.* 2015) by complete pedigree so far. Thirdly, our breeding program progresses could be prospects for future improvements in wood properties, cold-tolerant, wind-resistance and disease-resistance through genetic breeding and selection rather than growth traits. Due to the highly correlation with pulp yield, wood density is an important trait with respect to the value of eucalypt wood for pulp production (Wei and Borralho 1997; Schimleck *et al.* 1999; Phiura *et al.* 2007; Wu *et al.* 2010a; Wu *et al.* 2011b). Wu *et al.* (2011a) analyzed the genotypic variation and genotypic correlations in growth traits, wood properties and bark percentage for 19 hybrid eucalypt clones at three sites in southern China sampled at age 51 months and then conclude that breeding of eucalypt in China for pulpwood plantation should emphasize both on improving both wood properties and growth traits.

2.3 Clone Testing

In the past twenty years, there has been increasing interests in the part of many *Eucalyptus* breeding programs around the world in developing clonal forestry to enhance plantation productivity and wood properties, determine the best strategies for clonal testing and breeding, and predict genetic gains from deploying the best clones (Osorio *et al.* 2001; Osorio *et al.* 2003) because clonal testing could capture opportunity to estimate both additive and nonadditive genetic effects (Hai *et al.* 2008a; Kien *et al.* 2010).

In China, widely used eucalypt cultivation is based on a small number of clones (Pegg *et al.* 2006; Xiang *et al.* 2006; Zhang *et al.* 2013; Shi *et al.* 2015). Gan *et al.* (2006) reported the genetic distance of 25 clones and indicated that there was low diversity between them. These monoclonal or oligoclonal plantations of restricted genetic diversity carry potential risks of damage by pests and pathogens outbreaks or of inability to cope with extreme climatic conditions (Bueren 2004; Forrester *et al.* 2006; Pliura *et al.* 2007; Wu *et al.* 2015). Aravanopoulos *et al.* (1999) suggested that the utilization of multiclonal plantations in the form of monoclonal blocks should no greater than 5 ha and the use of about 10 clones per plantation in short rotation willow coppice will provide a satisfactory genetic base and accommodate the benefits of using clonal mixtures.

Together with other results (Li *et al.* 2006; Lu *et al.* 2004; Chen *et al.* 2001; Lu *et al.* 2005; Yao *et al.* 2003; Li *et al.* 2012), we deem that there are three factors that limit the development of eucalypt plantation in China. Primarily, the number of eucalypt clones available for mass distribution is still very limited, partly because the local breeding institutions are struggling to keep up with the demand from plantation growers for new clones (Bueren 2004).

Secondly, eucalypt clones should be selected for stable performance across a variety of environments to determine best strategy for clonal testing and predicting selection gains from deployment of the best clones, and knowledge of genotype by environment interaction due to its importance for testing design, selection and deployment in any tree improvement program (Kien *et al.* 2010). However, there are few reports on growth traits and wood properties of eucalypt clones carried out at more than two sites in China (Wu *et al.* 2011a; Wu *et al.* 2013). Thirdly, for maximum site productivity, rotation age should be when the peak of mean annual increment occurs (Mead 2005). According to our unpublished material, the rotation length of clones used in southern China should be more than six years or longer because the fast-growing plantations are managed for veneer and pulpwood production on rotations as short as 4 years (Xu and Dell 2002). Therefore, growth traits and wood properties affecting the veneer and pulping process and other purposes need to be simultaneously addressed in an efficient breeding program and better silviculture in China.

3 LOOKING FORWARD

The main target of sustainable management of eucalypt plantations is maintaining long-term productivity and high quality (Yang 2009). As the eucalypt plantation area expands, more and more problems have appeared, for example, inappropriate plantation and management, increasing diseases and pests, severe erosion of red soils, narrow genetic base and universal low-value utilization etc. To prevent these problems, we would recommend that:

3.1 Multiple-trait Selection

Research into improvements in wood properties, cold-tolerant, wind-resistance and disease-resistance should be undertaken through genetic breeding and selection. While more attention should be focused on utilization of plantation-grown *Eucalyptus* species for higher-value products, such as large timber board and medium density fiberboard (MDF) and other than pulpwood and fuelwood.

3.2 Multiple-Generation Improvement

Finally and probably most importantly, a breeding strategy should be developed to direct tree improvement and breeding work for *Eucalyptus* in China. The best strategy for breeding and improving eucalypts in southern China is to rely on multiple generations and use interspecific hybrid breeding to create clones, both ecologically and genetically.

3.3 Multiple-Technique Propagation

By now, cuttings and tissue culture are now widely recognized as two major methods for propagating plus trees to clones in clonal forestry. Propagation also has become a bottleneck in Eucalyptus breeding in China. Therefore, extensive research on propagation should be carried out for different species, combinations, clones and even plus trees.

3.4 Multiple-Method Breeding

More methods, such as molecular genetics, transgenic plantlets, ion implantation and tetraploid plants etc, should be used in breeding procedure in order to expand the frequency of favorable alleles or the frequency of specific combinations of favorable alleles in the breeding populations, and then to improve the performance of individual plants by through recurrent selection.

3.5 Multiple-Field Consideration

Comprehensive silviculture practices such as plantation spacing, fertilization, irrigation, thinning and pruning etc. should be carried out intensively over different species and clones for different cultivation goals at different sites over time to achieve *Eucalyptus* potential productivity. Meanwhile species and clones should be properly matched to site-type. The rotation period of eucalypt need to be extended from the current 4-6 to 6-8 years considering both the economic position of the forest farmers and the maintenance of site fertility.

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REFERENCE

[1] Aravanopoulos FA, Kim KH, Zsuffa L (1999) Genetic diversity of superior *salix* clones selected for intensive forestry plantations. Biomass & Bioenergy 16: 249–255

[2] Arnold RJ, Xie YJ, Midgley SJ, Luo JZ, Chen XF (2013) Emergence and rise of eucalypt veneer production in China. International Forestry Review 15(1):33–47

[3] Bai JY, Xu JM, Gan SM (2003) Genetic improvement of tropical eucalypts in China. pp. 64–70 in Turnbull JW Eucalypts in Asia Proceedings of an international conference held in Zhanjiang, Guangdong, People's Republic of China, 7–11 April 2003. Canberra, Australian Centre for International Agricultural Research Proceedings No. 111.

[4] Borralho NMG (2002) The challenges and lessons from breeding *Eucalyptus.* pp. 79–89 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[5] Bouvet JM, Vigneron PH, Saya A (2003) Trends in variance and heritabilities with age for growth traits in *Eucalyptus* spacing experiments. Silva Genetica 52(3-4): 121–133

[6] Bueren MV (2004) Eucalypt tree improvement in China. Australian Centre for International Agricultural Research, Impact Assessment Series Report No. 30

[7] Bull GQ, Bazett M, Schwab O, Nilsson S, White A, Magninnis S (2006) Industrial forest plantation subsidies: impacts and implications. Forest Policy and Economics 9: 13–31

[8] Chen SX and Chen XF. (2013) Technical Problems and Thinking on Eucalypt Plantation Management in China. Eucalypt Science & Technology 30:52-59 (In Chinese)

[9] Chen X, Ou S, Liang X, Zheng R, Zhao G (2001) Growth comparison of five hybrid *Eucalyptus* clones. Guangdong Forest Science and Technology 17(2): 11–14 (in Chinese)

[10] Danusevicius D, Lindgren D (2002) Clonal testing may be the approach to long-term breeding of *Eucalyptus.* pp. 192–209 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[11] Forrester DI, Bauhus J, Cowie AL, Vanclay JK (2006) Mix-species plantations of *Eucalyptus* with nitrogen-fixing trees: a review. Forest Ecology and Management 233: 211–230

[12] Gan SM, Li FG, Bai JY (2006) Application of protocols in molecular biology for eucalypt breeding. Guangxi Forest Science 35(4): 243–249 (in Chinese)

[13] Hai PH, Jansson G, Harwood C, Hannrup B, Thinh HH (2008a) Genetic variation in growth, stem straightness and branch thickness in clonal trials of *Acacia auriculiformis* at three contrasting sites in Vietnam. Forest Ecology and Management 255:156–167.

[14] Hai PH, Harwood C, Kha LD, Pinyopusarerk K, Thinh HH (2008b) Genetic gain from breeding *Acacia auriculiformis* in Vietnam. Journal of Tropical Forest Science 20(4): 313–327

[15] Hardy GE, Burgess T, Dell B (2002) Potential threats of plant pathogens to *Eucalyptus* plantation in China. pp. 358–366 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[16] Huang L, Dell B (2002) Database system approach for integrated plantation nutrition management. pp. 290–300 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[17] Kien ND, Jansson G, Harwood C, Thinh HH (2009) Genetic control of growth and form in *Eucalyptus urophylla* in northern Vietnam. Journal of Tropical Forestry Science 21(1): 50–65

[18] Kien ND, Jansson G, Harwood C, Almqvist C (2010) Clonal variation and genotype by environment interactions in growth and wood density in *Eucalyptus camaldulensis* at three contrasting sites in Vietnam. Silva Genetica 59(1): 17–28

[19] Kusnandar D, Galwey NW, Hertzler GL, Butcher TB (1998) Age trends in variances and heritabilities for diameter and height in

Maritime Pine (*Pinus pinaster* AIT.) in western Australia. Silva Genetica 47(2–3): 136–141

[20] Li D, Liu Y, Zheng H, Zhu R, Huang Y (2003a) Analysis of genetic effects on growth traits in Eucalyptus maidenii F. Muell. pp. 229–238 in Wei R, Xu D Eucalyptus Plantation Research, Management and Development. World Scientific Publishing Co. Pte. Ltd. 1–6 September 2002 Guangzhou, China.

[21] Li D, Liu Y, Zeng D, Zhong K, Fan L (2003b) Analysis of genetic effects for growth traits of Eucalyptus globules Labill. in a 6 × 6 diallel design. pp. 220–228 in Wei R, Xu D Eucalyptus Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[22] Li GY, Xu JM, Risto V, Jiang H, Tang Z, Lu ZH (2006) Growth and genetic analysis of *Eucalyptus urophylla* clones in three sites in Guangxi. Journal of Northwest Forestry University 21(5): 84–88 (in Chinese)

[23] Li GY, Xu JM, Lu ZH, Du ZH, Han C, Wu SJ, Wang W (2012) Growth and stemstudy on the clones of Eucalyptus in southern Fujian. Journal of Central South University of Forestry &Technology 32(4):21–25 (in Chinese)

[24] Li X, Hu TY (2003) Genetic resources of eucalypts and their development in Sichuan. pp. 123–125 in Turnbull JW Eucalypts in Asia Proceedings of an international conference held in Zhanjiang, Guangdong, People's Republic of China, 7–11 April 2003. Canberra, Australian Centre for International Agricultural Research Proceedings No. 111.

[25] Liang KN, Bai JY (2003) Selection on growth and wind-resistance traits for provenances and families of *Eucalyptus urophylla*. Forest Research 16(6): 700–707 (in Chinese)

[26] Liley B. (2014) Focus on China: Guigang - Anatomy of a Hardwood Revolution. Presentation to: 'Forest Investment & Market Outlook' Conference, 14-15 April, 2014, Melbourne Australia.

[27] Lin M, Arnold RJ, Li B, Yang MS (2003) Selection of cold-tolerant eucalypts for Hunan province. pp. 107–116 in Turnbull JW Eucalypts in Asia Proceedings of an international conference held in Zhanjiang, Guangdong, People's Republic of China, 7–11 April 2003. Canberra, Australian Centre for International Agricultural Research Proceedings No. 111.

[28] Liu Y, Xu JM, Qian G, Wu W, Li BQ, Wu SJ (2009) Study on cold-tolerant tree species/provenances introduction in northwestern Fujian of subtropical zone. pp. 67–73 in The Fourth Session Fifth Eucalypt Conference, Chongqing, 27–29 October 2009 (in Chinese)

[29] Lu GH, Lu ZH, Xu JM, Zhao RY, Li Y, Li GY (2003) Study on growth comparison between *Eucalyptus urophylla* clones. Guangxi Forestry Science 32(1):42–45 (in Chinese)

[30] Lu ZH, Xu JM, Bai JY, Zhou W (2000) A study on wood property variation between *Eucalyptus tereticornis* and *Eucalyptus camaldulensis*. Forest Research 13(4): 370–376 (in Chinese)

[31] Lu ZH, Xu JM, Lu GH, Zhao RY, Li Y, Li GY (2004) Study on integrated selection and estimation of the breeding value in *Eucalyptus* wetarensis provenences. Forest Research 17(2): 220–225 (in Chinese)

[32] Lu ZH, Xu JM, Li GY, Bai JY, Qi SX (2005) Integrated selection of clones from *Eucalyptus* species. Journal of Nanjing Forestry University 29(5): 61–64 (in Chinese)

[33] Lu ZH (2009) Genetic analysis of *Eucalyptus urophylla* intraspecific complete diallel and interspecific factorial crossing and multi-traits seclection of F_1. Ph. Degree thesis, Research Institute of Tropical Forestry, Chinese Academy of Forestry, China pp. 90–91 (in Chinese)

[34] Luo JZ, Zhou G, Wu B, Chen D, Cao JG, Lu W, Pegg RE, Arnold RJ. (2010): Genetic variation and age-age correlations of *Eucalyptus grandis* at Dongmen Forest Farm in southern China. Australian Forestry **73**(2): 69–82.

[35] Martin B (2002) *Eucalyptus*: a strategic forest tree. pp. 3–18 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[36] McKenney DW (1998) Australian tree species selection in China. Canberra, Canadian Forest Service Great Lakes Forestry Centre, ACIAR Projescts 8457 and 8848, Impact Assessment Series Report No. 8

[37] Mead DJ (2005) Opportunities for improving plantation productivity. How much? How quickly? How realistic? Biomass & Bioenergy 28:249–266

[38] Mo XY, Peng S, Long T, Chen W, Yang X (2002) Important traits and combined evaluation of eucalypt clones. pp. 102–108 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[39] Osorio LF, White TL, Huber DA (2001) Age trends of heritabilities and genotype-by-environment interactions for growth traits and wood density from clonal trials of *Eucalyptus grandis* Hill ex Maiden. Silva Genetica 50(1): 30–36

[40] Osorio LF, White TL, Huber DA (2003) Age-age and trait-trait correlations for *Eucalyptus grandis* Hill ex Maiden and their implications for optimal selection age and design of clonal trials. Theoretical Applied Genetics. 106: 735–743

[41] Pegg RE, Li H, Li H, Zhou G, Xiang DY (2006) Study on artificial breeding of eucalypt hybrid in Guangxi. Guangxi Forestry Science 35(4):238–242

[42] Pliura A, Zhang SY, Mackay J, and Bousquet J (2007) Genotypic variation in wood density and growth traits of poplar hybrids at four clonal trials. Forest Ecology and Management 238:92–106

[43] Qi SX (2002) Brief introduction of eucalypt cultivation and utilization in China. pp. 37–41 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[44] Qi SX (2007) Applied Eucalypt cultivation in China. Beijing: China Forestry Publishing House. (in Chinese)

[45] Schimleck LR, Michell, AJ, Raymond CA, Muneri A (1999) Estimation of basic density of *Eucalyptus globulus* using near-infrared spectroscopy. Canadian Journal of Forest Research 29 (2):194–202

[46] Shi ZQ, Jiang YD, Zhou ZZ, Zhang RG. (2015) The current research status of *Eucalyptus* in Yunnan province. Journal of West China Forestry Science 44(1):152–156

[47] Shield E (2002) Utilization of plantation-grown *Eucalyptus*: new resources…new approaches. pp. 375–391 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[48] Simpson JA, Pegg RE, Bai Z (2002) An overview of the response of eucalypts to fertilizer at Dongmen, southern China. pp. 253–268 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[49] Toit BD, Smith CW, Little KM, Boreham G, Pallett RN (2010) Intensive, site-specific silviculture: manipulating resource availability at establishment for improved stand productivity. A review of Southern African research. Forest Ecology and Management 259: 1836–1845

[50] Varghese M, Harwood CE, Hegde R, Ravi N (2008) Evaluation of provenances of *Eucalyptus camaldulensis* and clones of *E. camaldulensis* and *E. tereticorni* at contrasting sites in southern India. Silva Genetica 57(3): 136–141

[51] Wang H, Malcolm DC, Fletcher AM (1999) *Pinus caribaea* in China: introduction, genetic resources and future prospects. Forest Ecology and Management 117: 1–15

[52] Warren E, Smith RGB, Apiolaza LA, Walker JCF (2009) Effect of stocking on juvenile wood stiffness for three *Eucaluptus* species. New Forests 37: 241–250

[53] Wei RP (2002) Merging ecological concerns into sustainable management of short-rotation forest plantations in south china: practices by Sino-forest Corp. pp. 51–63 in Wei R, Xu D *Eucalyptus* Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[54] Wei XM, Borralho NMG (1997) Genetic control of basic density and bark thickness and their relationships with growth traits of *Eucalyptus urophylla* in south east China. Silvae Genetica 1: 32–36

[55] Wu KM, Wu JY, Gan SM (2001) Hybridization and heterosis in *Eucalyptus*. Guangdong forest science and technology 17(4): 10–15 (in Chinese)

[56] Wu SJ, Xu JM, Li GY, Risto V, Lu ZH, Li BQ, Wang W (2010a) Use of the pilodyn for assessing wood properties in standing trees of *Eucalyptus* clones. Journal of Forestry Research 21(1): 68−72

[57] Wu SJ, Xu JM, Li GY, Du ZH, Lu ZH, Li BQ, Wang W (2011a) Genotypic variation in wood properties and growth traits of *Eucalyptus* hybrid clones in southern China. New Forests 42:35−50

[58] Wu SJ, Xu JM, Li GY, Risto V, Lu ZH, Li BQ, Wang W (2011b) Estimation of basic density and modulus of elasticity of eucalypts clones using nondestructive methods in southern China. Journal of Tropical Forest Science 23(1): 51−56

[59] Wu SJ, Xu JM, Li GY, Lu ZH, Han C, Hu Y, Hu XX. (2013) Genotypic variation and genetic gain in growth traits, stem-branch characteristics and wood properties and their relationships to *Eucalyptus urophylla* clones. Silvae Genetica 62(4−5):218−231

[60] Wu SJ, Lu ZH, Xu JM, Chen GC, Zhu YA, Li GY. (2015) Genotypic variation in growth traits and stem-branch characteristics and their relationships to *Eucalyptus* clones. Journal of Forest Research (DOI 10.1007/s11676-015-0092-2)

[61] Wu SJ, Xu JM, Lu ZH, Li GY, Pan LQ, Han H. (2015) Effects of inbreeding on growth and wood properties of selfed *Eucalyptus urophylla* progenies. Journal of Tropical Forest Science 27(3) (Accepted)

[62] Xiang D, Chen J, Ye L, Shen W (2006) Present situation, problems and countermeasures of eucalypt plantations in Guangxi.

Guangxi Forestry Science 35(4): 195–201 (in Chinese)

[63] Xu DP, Dell B (2002) Nutrient management of eucalypt plantations in south China. pp. 269–288 in Wei R, Xu D Eucalyptus Plantation Research, Management and Development. Proceedings of the International Symposium held in Guangzhou, People's Republic of China. 1–6 September 2002 World Scientific Publishing Co. Pte. Ltd.

[64] Xu DP (2003) Scenarios for a commercial eucalypt plantation industry in southern China. pp. 39–45 in Turnbull JW Eucalypts in Asia Proceedings of an international conference held in Zhanjiang, Guangdong, People's Republic of China, 7–11 April 2003. Canberra, Australian Centre for International Agricultural Research Proceedings No. 111.

[65] Xu JM, Bai JY, Lu ZH (2001) Some sustainable strategies of improvement and breeding for *Eucalyptus* tree species in southern China. Forest Research 14(6): 587–594 (in Chinese)

[66] Xu JM, Lu ZH, Li GY, Bai JY (2003) Study on integrated selection of provenances-families of *Eucalyptus tereticornis*. Forest Research 16(1): 1–7 (in Chinese)

[67] Yang MS (2003) Present situation and prospects for eucalypt plantations in China. pp. 9–15 in Turnbull JW Eucalypts in Asia Proceedings of an international conference held in Zhanjiang, Guangdong, People's Republic of China, 7–11 April 2003. Canberra, Australian Centre for International Agricultural Research Proceedings No. 111.

[68] Yang MS (2009) Eucalypts research present situation and develop trend in China. pp. 1–10 in The Fourth Session Fifth Eucalypt Conference, Chongqing, 27–29 October 2009 (in Chinese)

[69] Yao QD, He S, Zhang J, Hong C, Li B (2003) Study on selection of *Eucalyptus* fine clone for fiber timber in southern hilly land of Fujian. Scientia Silvae Sinicae 39(1): 87–92 (in Chinese)

[70] Zhang ZY, Xiang DY, Deng ZY, Tang QL, Chen JB, Lan J. (2013) Establishment of fingerprinting for 24 clones in Eucalyptus. Journal of Northwest Forestry University 28(2):74–78 (in Chinese)

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