Challenges and prospects for seed orchard development in South China

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Abstract

This paper 1) briefly reviewed the history, development and status of seed orchard for different forest species, 2) discussed the difficulties or problems and the causes, and 3) proposed the solutions for further seed orchard development in south China. In the last four decades, many seed orchards were established, but most of them were the first generation with low realized genetic gain and many were not well maintained. Long-term seed orchard development should focus on major species for ecologically public-benefit forests and minor tree species. The idea of low-input seed orchard is particularly recommended. It is also proposed that newly growing private companies should greatly contribute to tree breeding and seed orchard through their involvement, input or cooperation.

Background

In South China, the first forest seed orchards were established in around 1964 after few years of preparation works such as plus tree selection, site selection, material collection, grafting etc. In the first decade, few species were considered, including Chinese fir (Cheng etc 1996; Qiu 2006) and slash pine (Zhu etc 1993). Chinese fir is one of the main wood production species in South China, while slash pine was introduced into Guangdong, China as early as in 1930s, and found well adaptive to the local environment (Zhu etc 1993). From 1975 to 1995, seed orchard programs were expanded or extended to more species but to the advanced generation only for few species (Cheng etc 1996; Chen etc 1999; DSOFF 2000; Yang 2001; Sun etc 2003; Qiu 2006). In the last decade, not really much progress was achieved even though forest plantation business has rapidly been booming up in the region.

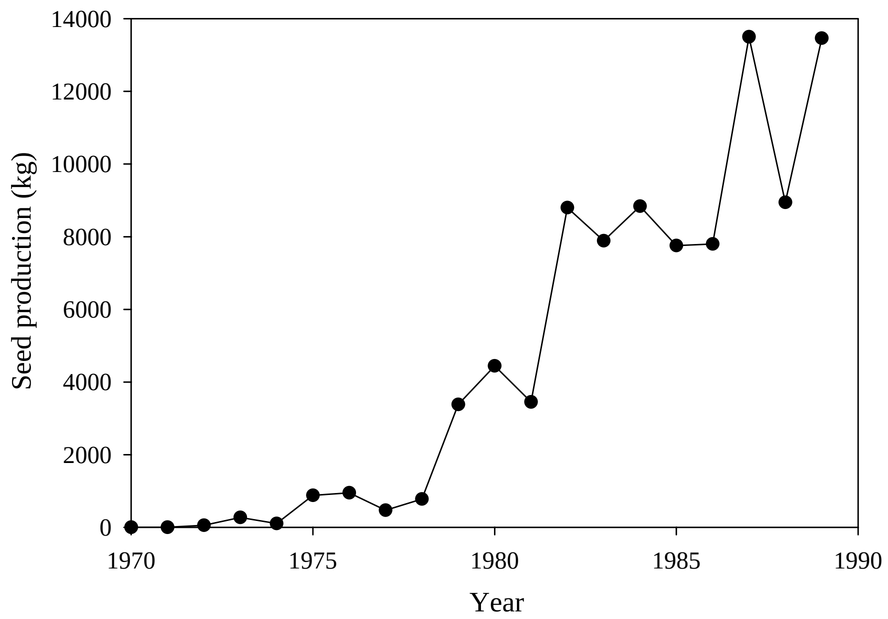
Up to date, most of the existing seed orchards are still in their first generation using plus trees as parent materials, and some in the advanced generation using genetic materials selected from progeny test trials (Shen 1992; Cheng etc 1996; DSOFF 2000; Sun etc 2003; Li etc 2005; Qiu 2006). Most of the seed orchards were/are located at, owned and managed by state-own forest farms and tree breeding bases that are under local forest bureaus or state-own forest companies. Technically, they are parts of the national & provincial tree breeding programs, and usually planned, designed and advised by forest geneticists from local universities or research institutes. On the other hand, these state-own forest farms or tree breeding bases are often managed as financially independent units.

More than 30 species were once put in seed orchards, including pines, Chinese fir, casuarinas, teak, eucalypts, acacias, *Castanopsis hystrix*, *Sassafras tzumu*, *Taxodium distichum*, *Taiwania flousian* etc (Shen 1992, 1994; DSOFF 2000; Bai 2004; Li etc 2005; Liang etc 2006). Some species might be included in more than one seed orchard, depending on the planting or replanting plan early made by national or local governments. These seed orchards naturally differed in area, management intensity and output.

Seed orchards were usually well designed and planted according to the standard textbooks (e.g. Faulkner 1975; Jiao etc 2004). It was planned that the parental materials covered relatively wide ranges of the natural distribution although actual plus-tree selection might not be so. Large amount of the selected genes were collected and exclusively conserved in the early established seed orchards. These collections were supposed to constitute the fundament not only for then seed orchard establishment but also long term breeding.

Some seed orchards flowered quite early and had good seed production as expected, providing huge amount of improved seeds for afforestation or reforestation. In a slash pine seed orchard located in south Guangdong, for instance, the grafts was planted out with a total

Fig 1. Seed production over ages for a slash pine seed orchard planted from 1965 to 1969 and expanded from 1974 to 1978 in South Guangdong



area of 60 ha from 1965 to 69, among which 6 and 20 ha were planted in 1965 and 1966, respectively; and an expansion of 50 ha with the same genetic materials was carried out from 1974 to 1978. The grafts started to flower at 4-year old and produce seed at 5-year old (Zhu etc 1993). The total seed production steadily increased from 1970 to 1989 (Fig 1). By the end of 1989, the accumulated seed production was 91,800 kg, which accounted for most of seed sources for slash pine planting before 1990 in south China. It was also observed that slash pine grafts had fast growth in cone production during the period from 8 to 14 years old and reached peak stage from 15 years. A caribaean pine orchard planted in 1974 started to flower at 3-year old and produced 300 kg cone or 15 kg seed per hectare at 8-year old (Zhu etc 1986).

Many seed orchards or even breeding bases were abandoned or converted to other uses due to poor management, deficient capital, less seed demand, low profit, high maintaining cost, land use change or economic development in the last decade. Seed orchards might not have enough budgets from national or provincial funds or income from seeds for maintaining their seed orchards (Wang etc 2006). Most of the early seed orchards aimed at improvement of growth. It was expected that some genetic gain could be obtained with use of seed orchard seed (Shen 1992, 1994). It seemed however that realized gain was generally lower than expected, if we look into the growth rate of plantations planted 10 or 20 years ago.

The definition of seed orchard is diverse. It is restricted in this paper to the sense of conventional or traditional mass-multiplication of genetically improved seed crops (Faulkner 1975). Almost all of early or existing seed orchards in south China were or are conventional. This paper discussed the issues and prospects of seed orchard development from seven perspectives, and particularly recommended low-input schemes for establishing and managing new seed orchards.

Ownership

Most of the existing seed orchards were/are owned and managed by state-own forest farms or breeding bases that do not have regular financial support from governmental budget or enough income from selling seeds (Li etc 2005; Wang etc 2006). This has been a key issue for maintaining or improving seed orchards since economic reform in the country. Few private companies may have their own seed orchards in the last several years, but they are technically still supported by the existing breeding programs. It could be expected that there will be a change in seed orchard ownership in the soon future.

Private companies become more and more important in managing commercial timber plantation forests. Desire of using improved materials including seeds in their planting is a strong drive for them to get involvement in seed orchard development. They may directly buy seed from the existing seed orchards for their short time purpose, or operate their own seed orchards for long run. A fast and efficient way is probably to change ownership through cooperation in maintenance and improvement of the existing seed orchards, as well as in establishment of new seed orchards. Private sector should play a major role in breeding programs and seed orchards, particularly for commercial plantation species. In the other hand, non-commercial planting with improved seeds is the country's long-term strategy to increase forest resources and protect environment (NFA 2006). The continuous investment of the public agencies is thus essential. In addition, there may appear professional breeding companies that operate seed orchards purely for commercial purpose.

Private sector or professional companies could focus on main commercial species such as eucalypts, pines, Chinese fir, and other fast-growing and high-value species, while state-own forest farms or breeding bases should pay more attention to species of both commercial and ecological values. As a most sustainable stakeholder, governmental support is also indispensable for commercial species. No matter what kind of ownership, a seed orchard may involve many different parties including shareholders, land owner, gene owners, technical contributors, seed users, local forest bureaus, local communities etc (stakeholders). Harmony cooperation among stakeholders is obviously a key for success of a breeding program as well as seed orchard management.

Investment and infrastructure

It has been a rule of thumb that good infrastructures with heavy investment are necessary for operating a seed orchard (Cheng etc 1996; Qiu 2006). These infrastructures include good land, transportation, irrigation, electricity etc. High-input is a psychological threshold to pass in planning and establishing new seed orchards for both public and private sectors. This has also been a main cause for instability of the early or existing seed orchards, particularly since market economic was adopted (Wang etc 2006). As the population is large and wide-distributed, and economic has been developing so fast in south China, many early seed orchards were converted for expansion of township, and construction of high-way, residence and factory. In addition, it seemed that the state or provincial policy support for funding tree breeding and research has gradually been switched from tradition breeding including seed orchard to molecular genetics and gene engineering in the last decade.

Is low-input seed orchard feasible? I give a very positive answer, at least in China and some developing countries. Ordinary forestland, usually hilly or mountainous lands in south

China, should be acceptable, even more suitable for producing improved seeds. Irrigation system is not necessary as rainfalls are usually high (>1200 mm) and relatively even in South China (e.g. Cheng etc 1996; CMA 1998). Simple forest road or access is perhaps enough. Other infrastructure investments may not be necessary or can just be low.

Technical operations and management can be simple and less costly (Lindgren and Wei 2006). Imagine a seed stand with mother trees designated and deployed as in a seed orchard. It may be a little bit more expensive to collect fruits or cones, but much cheaper in general. It may be less productive, but the production may be well enough for localizing or less overspreading the genetic materials. Such a low-input seed orchard has other advantages: 1) less likely to be changed for other purposes, 2) less human disturbance, 3) easy to maintain, and 4) flexible management. I will further discuss the potential low-input seed orchard management below.

Planting species

Main planting species varied much over time, although large scale planting has never been stopping in the last few decades (NFA 2006). Such change was more or less political, rather than scientific, technical or industrial-demanding. Before 1980s, the main planting species were Chinese fir and pines. In 1980s and before mid 1990s, the planting was switched to the southern pines including slash pine, loblolly pine and caribaean pine. Since late 1990s, eucalypts have been predominating over the whole region. A direct consequence was change in demand on specific species seed. This created great difficulties for maintaining high-input seed orchards.

Forest industry, particularly plantation business was opened up to private sector only in the last decade. Along with more involvement of private sector in forest resources, market demand will certainly regulate planting species to a more sensible and stable structure. This is very favorable for seed orchard management and development. It can also be predicted that more species would be considered for commercially planting as market economic develops.

In China, planting is not only adopted for commercial plantations but also for regenerating or rehabilitating other types of forests, which is a great drive for seed orchard development (Li etc 2005). It would always be a desire to use improved materials in planting. Sustainable harvesting with replanting is a development direction, which leads to a more stable demand on seed orchard seeds. Sexual propagation is still the main avenue for many species, which underlies the basis for developing seed orchards.

Gene resources

Plus tree selection work might not well cover the natural distribution of a species. Useful genes in nature might be missed in generating new planting materials. Gene stock deployed in a seed orchard might not well adapt to the planting region because proper breeding zones or seed use guidelines were usually not available. Lots of early selections were lost, not tested, or not deployed in seed orchards. Deployment of initially selected genes without testing could result in high genetic diversity that was probably unnecessary, since the number of deployed clones was usually large (Ai etc 2006; He 2006; Hong 2003). Pollen contamination was not much recorded but observable (Lai and Chen 1997), undesired for gain but a way to maintain high diversity. All of these issues should partly explain low realized gain in plantations.

Early used genes were exclusively kept in seed orchards, and many of them might be lost along with the disappearance of some seed orchards. In the other hand, the natural or secondary forests of many indigenous species become less and less, meaning a rapid loss of gene resources. It is an urgent task to conserve the plus trees early selected, and to collect valuable genes from the wilds. To conserve gene diversity for future improvement and seed orchard development, we need to consider an efficient cooperation that is different from a tradition one. Private sector should play a major role in strengthening gene conservation, seed orchard management and financial support. Through cooperation, an effective mechanism should be established so that the existing gene collections are best used, and the breeding and seed orchard programs best benefit from exchange of the gene resources.

Technically, it is of great potential to explore genetic gain through intensive and optimal use of genes in seed orchards. For exotic species, more gene resources are always positive for generating high gain, such as eucalypt improvement in China (DSOFF 2000). Early cooperation with foreign institutes in species and genes introduction was exclusively carried out by the state-own institutes such as forest farms, breeding bases, universities and research institutes. It becomes possible now for private sector to get involved in such cooperation, particularly as more and more foreign forest companies invest in China.

Breeding program

Well breeding strategy and/or plan were considered in the beginning for some species such as Chinese fir and loblolly pine. The corresponding seed orchards were established with sound design, technical input and management. However, such breeding and seed orchard operation usually could not continue as planned, because of less seed demand, deficient input and other undesired difficulties (Wang etc 2006). For many species, breeding work started with a simple breeding plan, or plus tree selection and seed orchard establishment. Technical input into seed orchards was usually not enough to ensure the expected genetic gain. In addition, almost all breeding programs were initiated and planned by universities or research institutes, but operated or managed by the financially and administratively independent units such as state-own forest farms and breeding bases, which was not favorable for effectively sustaining the breeding programs and improving gains.

A seed orchard is usually part of a breeding program. As market economic and private forest resources further grow, seed orchard development would mainly rely on the genetic quality of seeds produced. A successful breeding program with sound strategy and plan underlies the technical basis for a seed orchard with good output. However, most of breeding programs progressed slowly, or were not systematic or effective to support seed orchards with high gain, which was obviously inconsistent with the potential output. Private sector is young in this country, and it is difficult to say now how far they would like to go with their own tree breeding programs. A most quick, realistic and efficient way to better existing or work out new breeding and seed orchard programs is to effectively integrate the interests of all potential stakeholders. With improved strategy and plan, most existing breeding and seed orchard programs may greatly benefit in terms of sustainable operation and gain improvement.

Genetic testing of the breeding population materials is an indispensable part of tree breeding and seed orchard, which basically include 4 levels of trials: provenance, half-sib, full-sib and clonal. While seed-lots with provenance and half-sib structure were sometimes considered, most full-sibs with specific crossing design often came with the second and later generation breeding. Cloned materials may be used alone or combined with a high hierarchical structure in trials. Half-sib family trials that should be used to test the general performance of seed orchard seeds were often used for selection of parents for the next cycle of breeding.

Most breeding or seed orchard programs involved provenance or half-sib trials, even at late stage when crossing work could be easily achieved (DSOFF 2000). Some of them had good materials and experiment design. Full-sib family or hybrid trials were set up for several important species, such as eucalypts, pines, Chinese fir etc. However, only several advanced generation seed orchards were established. Clone testing becomes poplar in the last two decades, but mostly used for screening superior clones for plantations (DSOFF 2000). Common issues for genetic trials probably included too few genetic entries (20~30) or test sites (1~4) for improving the genetic quality of the existing or planned seed orchards.

Sound genetic testing should be emphasized to obtain high gain through improving the accuracy of genetic parameter estimates, seed orchard thinning or seed collection, selection of parents for the advanced generation breeding or seed orchard, and deployment of genetic materials in plantations. Large number of genetic entries in trials would definitely increase the sampling accuracy of genes, and intensity of selection. Properly increasing test sites would reduce the sampling skewness in representing normal planting lands.

Mating issue has long been neglected in terms of efficiency, necessity, operability, cost etc. Good crossing work was carried out for very few species such as some eucalypt species and Chinese fir (DSOFF 2000). Crossing is one of the most costly and difficult operations in practice. Systematic mating design with strong theoretical support is necessary for efficiently advancing breeding as well as seed orchard. This is particularly important when setting up completely controlled or two or few clones seed orchards. Open-pollination is still most realistic for most of species in terms of cost and operation. A wide genetic base with more parents or families is more effective for screening superior seed orchard materials (Lindgren etc 1997). A mating scheme should be planned by taking existing genetic knowledge, cost, operability, genetic testing and selection, sustainability etc into account. This is not easy but a direction for main commercial plantation species.

Selection of materials for seed orchards mostly aimed at growth traits such as height and DBH, but seldom at wood quality and other traits. It has been shown however that other traits such as wood density and fiber property would be as important as growth (e.g. DSOFF 2000). Genetic bases for selection were usually low, particularly those with a provenance or family structure because of low number of entries. Selection methods used such as family selection and between- and within-family truncation (He 2006; Hong 2003), were usually less efficient (Wei etc 1998). This was one of the main causes for the low realized genetic gain. Breeders should properly consider different traits of importance in selection for their final wood products. Overall gain could markedly be improved through properly widening genetic base or breeding population for intensive selection. In addition, selection or use of selections could be optimized to improve gain, diversity, and/or both in seed orchards.

When there was a demand, seeds from a seed orchard were often used in wide planting range, out of its targeting region. This has been an issue relating to breeding or seed zone. It was not considered when planning a seed orchard, neither when distributing the seeds (e.g. Xu and Liu 2002). For example, slash pine seeds from the earliest seed orchard in south Guangdong had once been used in more than 10 provinces (Zhu etc 1993). A direct lesson was that stands or trees did not perform well with slow growth and less resistance to insects or disease soon after planting. This work needs to seriously be considered in the future. Sound genetic trials that include rich materials and well cover the planting range are fundamental for delineating breeding or seed zones.

Vegetative propagation

Great progress has been achieved on mass vegetative propagation technology for many forest species. In China, cutting has been adopted in propagation of eucalypts, casuarinas, teak, Chinese fir, pines, poplars, Paulina, etc, and tissue culture for most eucalypts, teak, Paulina etc. Both cutting and tissue culture technology becomes more and more mature, and less and less costly over years for some eucalypts. It is particularly worthy to note that cutting materials have exclusively been used in planting of poplars and main eucalypt species for some years. Two years ago, some planters started to directly plant eucalypt tissue cultured materials in their plantations, and raised a high demand this year. It is predicted that tissue cultured material would replace cuttings in some years at least for some main eucalypt species, such as *E. urophylla*, *E. grandis* and their hybrids. This is probably one of the technological advantages that China has over other eucalypt planting countries. However, difficulties exist in using cutting or tissue culture technology to mass propagate some species for large scale planting, such as *E. dunnii*.

Somatic embryogenesis is an attracting direction in tree species vegetative propagation. Progress has been made for mass propagation of conifer species in some countries. Most of efforts were restricted to lab research in China (Wang etc 2007). However, people see a bright future in advancing this technology for some pine and other commercial species that are difficult to root. It is also believed that vegetation propagation would become predominant in propagation of planting materials for many tree species.

A seed orchard is needed or survives only when seed is needed for planting programs. Asexual material has many advantages over seed orchard seeds. Most commercial planters prefer cloning material. Will vegetative propagation become a competitor or terminator of traditional seed orchard? Success in vegetative propagation would no doubt marginalize seed orchard development in China. A good example is short-rotation eucalypt species such as *E. urophylla*, *E. grandis*, *E. tereticornis* and/or their hybrids, changing quickly from seedling (seed orchard), rooting to tissue-cultured cuttings in the last decade. As vegetative technology matures for many tree species, seed orchard existence may highly rely on non-technical legal regulations that are necessary for ecological, environmental or social concerns. Ecologically public-benefit forests are quite likely to become the first target of such legal regulation, using seeds or seedlings for replanting or rehabilitation. It would be difficult and unlikely to have similar regulations for commercial plantation species.

Management

In this part, I would mainly focus on management skills and technologies that are different from traditional ones, particularly the idea of low-input seed orchard or breeding (Lindgren and Wei 2006). First, breeders should probably consider sites that are stable and less likely to be converted to other uses like house or factory building. Ordinary plantation lands (hills or low maintains) should be acceptable. Forestland for ecologically public-benefit may be a good choice as this type of land is relatively stable and less disturbed by human according to the national or provincial regulations. Good infrastructure (transport and irrigation systems) is not necessary as discussed above.

Genetic quality of seeds from a low-input seed orchard should be the same or similar to those from traditional ones, resulting from breeding operation. Seed production is not a sole goal; timber production or ecological and environmental functions should also be considered. The multi-objectives may properly be adjusted according to the changing demand on seeds, through control of mother tree density. This is a cost-effective way to set up and secure a seed orchard. Seed orchard seed crop could be considered superior over asexual materials in conservation.

To guarantee genetic improvement, the same genetic materials as for traditional seed orchards should be used, such as selection grafts, cuttings, or seedlings. Conventional design and layout can still be valid (Faulkner 1975; Jiao etc 2004), but site topography needs to be considered. To keep the cost further low, half-sib family seedlings (no crossing) or cuttings of selections are probably good materials, at least for most of minor species. Optimal reselection or deployment of materials can be employed in such seed orchard to obtain high quality seeds.

Initial planting density could be relatively high, something between for a traditional seed orchard and a normal stand or seed stand. Thinning is considered for both seed crop and wood growth, and certain number of trees is remained to ensure the final wood production. However, it is flexible for late-stage adjustment of the objectives, depending on the need on seeds. Trees are more like timber production trees rather than fruit trees. Logs of large size are obtained at a rotation age deliberately considered. Density control through thinning as well as tending should also take ecological or environmental considerations into account.

Seed orchard site should be maintained at a status of more or less “nature”, with enough vegetation and less soil disturbance to control soil and nutrition erosion. However, it is also necessary to minimize the growth competition on space and nutrition of vegetation with mother trees. It is probably feasible to only keep low layer vegetation between tree rows. Weeding is only given within certain distance around trees, when trees are young or short, and when seed crop is harvested. Fertilizing is given together with weeding to ensure enough nutrition supply for tree growth or seed production. Hormone chemicals such as $GA_{4/7}$ may be used to stimulate flowering and seed yield.

Seed crop harvest is difficult not only for low-input seed orchards as proposed, but also for traditional ones, as manual collection is still popular. Mother trees in low-input seed orchards should be taller. It may be argued that operations such as grafting, seed crop harvest, field layout etc are expensive. In the labor-intensive countries like China, however, the costs for these operations can still be low. Seed yield per unit area may be low, but this issue can probably be solved by increasing the area or few more sites.

Conclusions

Seed orchard development has a more than 40-year history in south China. Most of the seed orchards were in the first, and some in their advanced generation. Many were discarded due to conversion of land use, less input, no seed demand, etc. The last decade was probably a relatively difficult period for seed orchard development. The ownership, concept of seed orchard including needs of high-input and good infrastructure, varying species, and vegetative propagation technology were the main factors that created difficulties in developing seed orchards. The problems existing with gene resources, breeding program and management were the main causes for the slow progress in seed orchard and low realized gain in plantations.

Private sector would play a role in improving the existing or future breeding program and seed production. Asexual materials may be just super and become predominant for commercial plantations. There exist rooms for seed orchard even in the future with better vegetative propagation technology. Seed orchard should be a good choice for major ecologically public-benefit forest species and many minor tree species. Low-input seed orchard and breeding is probably a realistic alternative with well theoretical support, at least for developing countries or regions.

A low-input seed orchard does not need good land, good infrastructure, heavy construction and intensive tending (weeding, fertilizing, thinning, topping, pruning etc). Besides seed production, it also serves as other functions such as timber production, ecological or environmental conservation, or cultural appreciations. Its parent materials and layout should be the same as or similar to those for a traditional seed orchard. The initial planting density may be high, and flexible for adjustment later if needed.

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(Most in Chinese with English abstract)

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