BREEDING TROPICAL AUSTRALIAN ACACIAS

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Abstract: There are over 1200 species in the genus *Acacia,* over 900 of them in Australia. Plantations of four fast-growing species of the section *Juliflorae,* subgenus *Phyllodineae: Acacia mangium, A. auriculiformis, A. crassicarpa* and *A. aulacocarpa* are becoming important wood sources for paper and timber in south east Asia. These species grow naturally in northern Australia, Papua New Guinea and Irian Jaya (Indonesia).

Introductions of *A. mangium* to south east Asia began in the 1970s when seeds of a single tree collected at Mission Beach in Queensland were grown in Sabah (Malaysia). This initial introduction produced a land race of poor vigour. Earlier informal introductions of *A. auriculiformis* similarly resulted in land races of poor form and vigour. Representative provenance collections of the four species were made by CSIRO in the 1980s and tested not only in Sabah, but more widely in Indonesia, Malaysia, Thailand, Vietnam, and China. Superior provenances, mostly from Papua New Guinea, have been identified and results suggest there is relatively little provenance-by-environment interaction. Many operational plantation programs now use bulk provenance seedlots collected from the best known provenances.

Controlled pollination in these tropical *Acacia* species is very difficult and so breeding is largely based on open pollination. Trees flower and set seed within 3-4 years of age and so present the opportunity for rapid genetic improvement through quick turnover of generations. Open-pollinated breeding populations and seed orchards representing a broad genetic base of the best provenances of *A. auriculiformis* and *A. mangium* are now established in many south east Asian countries and in north Queensland, Australia, with a number of second-generation breeding populations already planted. Some countries have begun similar improvement programs with *A. aulacocarpa* and *A. crassicarpa.*

The interspecific hybrid between *A. auriculiformis* and *A. mangium* shows outstanding form and vigour in some tropical environments and, like the parent species, can be propagated from basal cuttings of young (up to 3 years old) trees. This provides an option for accelerated genetic gain through clonal forestry.

Keywords: Acacia, genetic improvement

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Acacia species native to Australia have been planted in over 70 countries and the area of plantations totalled approximately 1,750,000 ha in 1996 (Australian Tree Seed Centre estimates). Doran (1997) provides species profiles for the most promising Australian acacia species. *Acacia mearnsii,* native to temperate south eastern Australia, is widely planted in southern and central Africa and Brazil (200,000 ha), providing fuelwood, pulpwood and tannin from the bark. *Acacia saligna,* from south western Australia, is widely planted for fuelwood and animal fodder in north Africa and the Middle East. *Acacia colei* and *A. holosericea* from the subtropical dry zone are planted in semi-arid regions of Sahelian Africa and India for fuelwood, and their edible seeds are now being evaluated as a source of human food (Harwood 1994, Thomson *et al.* 1994).

The largest areas of *Acacia* plantations comprise two species from the tropical humid/subhumid zone, *A. mangium* and *A. auriculiformis,* now widely planted in lowland tropical and subtropical south east and southern Asia and southern China. (Table 1). *Acacia crassicarpa* and to a lesser extent *A. aulacocarpa* are also becoming important plantation species in these regions. The area of plantations is currently expanding very rapidly, particularly in Indonesia, and is expected to more than double by the year 2010. *A. mangium* has been found to be one of the tree species most effective for afforestation of *Imperata* grasslands which cover an estimated 20 million hectares in south east Asia (Turvey 1994). Some plantation estates such as that of SAFODA in northern Sabah, Malaysia, have established *A. mangium* plantations primarily on *Imperata* grasslands, but many other operations are planting on cut-over tropical forest.

Table 1. Plantation areas in 1996 of tropical *Acacia* species in south east Asia (primarily *A. mangium* and *A. auriculiformis)* (Source: ATSC estimates).

Country	1996 plantation area (ha)	Anticipated plantation area 2010
China	70,000	150,000
Indonesia	500,000	1,800,000
Malaysia	91,500	980,000
Papua New Guinea	10,000	?10,000
Philippines	45,000	?45,000
Thailand	20,000	50,000
Vietnam	80,000	150,000
Total	**815,500**	**>3,185,000**

Acacias are nitrogen-fixing members of the family *Leguminoseae,* sub-family *Mimosoideae,* and there are over 1200 species in the genus world-wide, more than 700 native to Australia. (Pedley 1981). The taxonomy of such a large genus is dynamic and there have been attempts recently to split it into three new genera *(Acacia, Senegalia* and *Racosperma,* Pedley 1987). Of these three groups of species one *(Acacia)* has species with bipinnate-leaves and spiny leaf axils growing mostly in Africa, Asia, South America, the second *(Aculeiferum)* consists of prickly vines or small trees widely distributed in the tropics, and the third *(Heterophyllum)* is mostly restricted to Australia and nearby islands. *Heterophyllum* contains both non-spiny, bipinnate-leaved *(Botrycephalae* and *Pulchellae)* and phyllodinous (where "leaves" are flattened stems) species (Pedley 1981).

This paper reviews the genetic improvement of *Acacia* species, focusing primarily on the tropical species *A. mangium, A. auriculiformis, A. crassicarpa* and *A. aulacocarpa* which have recently attained importance as plantation species. These are phyllodinous species belonging to the section *Juliflorae* in the *Heterophyllum* subgenus.

BIOLOGICAL CHARACTERISTICS

Australian acacia species, like most legumes, fix nitrogen through a symbiotic relationship with *Rhizobium* bacteria. This makes acacias useful in increasing organic matter without affecting sometimes precious nitrogen resources in the soil. Some strains of *Rhizobium* are more effective than others, and inoculation with superior strains in the nursery has been demonstrated to produce significant increases in biomass production of *A. mangium* in the field, in some exotic environments (Dart *et al* 1991, Galiana and Prim 1996). However, little attention is paid to *Rhizobium* strains in the southeast Asian countries where acacias are planted most widely, because nodulation occurs naturally in nurseries using forest topsoil in the potting mix, without artificial inoculation.

Flowering. In favourable environments, flowering of *A. mangium* occurs when trees are only 1.5-3 years old. *A. auriculiformis, A. aulacocarpa and A. crassicarpa* tend to be slightly less precocious but all will set seed within 3 years under the most favourable conditions. In the natural range in north Queensland, flowering of these species is seasonal, occurring mainly between March and May. Individual trees typically have several flowering flushes over this period. Seeds are mature by October-November. At equatorial latitudes in Malaysia, flowering and fruiting occur sporadically throughout the year, but usually with one or more major flushes (Zakaria 1993).

The inflorescence of *Juliflorae* acacias is a spike formed of many flowers (Sedgley 1987). Pollen grains are grouped into polyads (Kenrick and Knox 1982) consisting of 16 grains (4, 8, 12, 16, 32, 64 in other spp). Flowers are mostly hermaphroditic (only 4% staminate, Zakaria 1993), but although other acacias are protogynous (Sedgley 1987), Zakaria (1993) reports that in *A. mangium* there is synchronous emergence of stigmas and stamens with stigmas becoming receptive after stamen dehiscence. Other reports (eg Sedgley and Harbard 1993) suggest that this species too is protogynous.

16-grained polyads are formed from a single sporogenous cell by two mitoses followed by a single meiotic division (Kenrick and Knox 1979). When stigmas are pollinated by a single polyad, all resulting seeds have the same male parent although there are still differences among the seeds, the products of different meioses. In studies of *A. melanoxylon* (a related species with 16-grained polyads), Muona *et al.* (1991) found that a small but varying proportion (8-15%) of seed pods contained seeds derived from two or more male parents. They also found that different pods within the same inflorescence were more likely to have the same male parent than pods from different inflorescences. If these findings apply to the tropical species under consideration here, it has considerable implications for estimates of genetic parameters and for breeding strategy. When collecting seeds for progeny tests, too small a sample of pods and pods from the same inflorescences will lead to very high full-sibbing rates among progeny. To capture a high level of genetic diversity in seed collections it is necessary to collect many pods from different parts of the crown of each tree.

Controlled pollination techniques have been developed for acacias (Sedgley *et al.* 1992a, Jiwarawat *et al.* 1996) but have yet to become adopted widely. The number of control-pollinated seeds which can reliably be produced by a skilled worker is low - only 100-200 or so per week of full-time work. This would make it very expensive to regenerate a large breeding population through controlled pollination.

<u>Mating system.</u> Most acacias seem to have high rates of outcrossing (Sedgley 1987). Multilocus estimates for two natural populations each of *A. crassicarpa* and *A. auriculiformis* suggested extremely high outcrossing rates with little variation among populations (Moran *et al.* 1989a). This suggests that deviations from half-sibbing among progeny resulting from open-pollination will be derived from pollination by the same non-self male parent (via polyads) rather than from self-pollination. *A. aulacocarpa,* closely related to *A. crassicarpa* also had very high outcrossing rates (McGranahan *et al.* 1997). Further isozyme studies on 7 natural populations of *A. auriculiformis* provided estimates of multilocus outcrossing rates ranging from 0.67 to 0.95, the lowest being from a population in the Northern Territory which had low genetic diversity (Wickneswari and Norwati 1995). Reliable estimates of outcrossing have not been obtained for *A. mangium* because it exhibits extremely low levels of heterozygosity at isozyme loci (Moran *et al.* 1989b). Recent studies using RFLP markers (Butcher *et al.* 1996) have revealed higher levels of genetic variation in this species and outcrossing estimates could be made using these markers.

The most important pollination vectors for the tropical acacias under review here are believed to be insects, particularly bees which carry pollen polyads trapped on their hairy bodies (Sedgley *et al.* 1992).

HYBRIDS.

The best-known hybrid among the tropical acacias is that between *A. mangium* and *A. auriculiformis.* It was first recognised in Sabah in 1972 growing amongst roadside planted trees (Pinso and Nasi 1991). It is thought that it originated from planted trees of *A. mangium* crossing with nearby wildlings of *A. auriculiformis* introduced many years earlier (Mr Shim Phiau Soon pers. comm. 1992). Some hybrid individuals have shown outstanding growth in some environments (eg Sabah, Lapongan 1987, and Vietnam, Kha 1996). Its morphological characteristics (eg phyllode shape, size and venation, Kha 1996, and pod shape) seem to be intermediate between the two parent species but there appear to be more staminate flowers, particularly at the base of flowering spikes (Kijkar 1993). Interest in the hybrid has led to the establishment of biclonal seed orchards of the two species in Sabah (Griffin *et al.* 1991). It is relatively simple to identify hybrid seedlings in the progeny of either species (Gan and Sim 1991). Options for vegetative propagation are similar to those of the parent species (see below). Although not necessarily a disadvantage, the hybrid has very low seed set. Progressive decline in growth rates observed in successive generations of plantings in Sabah (Sim 1984) could have been due to hybrid breakdown (Mr Shim Phiau Soon pers. comm. 1992) as much as inbreeding depression (see below).

VEGETATIVE PROPAGATION

It is easy to propagate young seedlings of these three species by stem cuttings, but the ability to form roots drops rapidly after 12 months of age. Dams (1991, 1993) obtained 71% success with 6 month seedlings of *A. mangium*, but by 12 months, this had fallen to 31% and by 24 months was only 15%. Similar results for *A. mangium* were obtained by Monteuuis (1995). Coppicing of 3-year-old selections of the *A. mangium* x *A. auriculformis* hybrid in Vietnam and cutting propagation of resprout shoots enabled 21 of some 60 selections to be brought into large scale propagation for clonal testing, other selections had to be abandoned because they rooted poorly.

Coppicing is not vigorous or reliable, so these species cannot be grown on coppicing rotations.

High success rates (70%) have been obtained by using marcots on adult trees (Sim 1987). Marcotting does not fully restore juvenility and rooting ability. Young shoots from some marcots can be used as cuttings to produce ramets of a clone (Wong 1988), but rooting vigour of such cuttings is not good enough for operational clonal forestry.

Propagation of juvenile material is also possible by micropropagation; Dams (1991) used nodal explants to obtain cultures from 1-month-old germinants. He claimed it was possible to obtain shoots after 2 weeks and multiplication rates of about 20-30 per explant, but in his experiments the rooting percentage fell from 60-70% in initial cycles to 50% at cycle 6 (Darus 1993). This drop in rooting percentage with repeated cycles of cuttings in tissue culture was not matched in studies of cutting propagation reported by Wong and Haines (1992) in *A. mangium* and *A. auriculiformis.* Haines and Griffin (1992) suggest that stem cuttings are adequate for vegetative propagation of these tropical acacias and the hybrid *A. mangium* x *A. auriculiformis* that tissue culture offers insufficient advantages to warrant wide adoption. However, tissue culture does have the capacity to achieve at least partial rejuvenation of selected genotypes by culturing axillary buds of trees several years old, in the case of the *A. mangium* x *A. auriculiformis* hybrid (Kha 1996), although it is unclear to what extent it can restore good rooting ability in hard-to-root genotypes.

Acacia mangium, A. auriculiformis and *A. crassicarpa* all occur naturally in coastal sub-coastal north east Queensland, south west Papua New Guinea and adjacent south east Irian Jaya (Pinyopusarerk 1990, Thomson 1994, Butcher *et al.* 1996). *A. mangium* also occurs on the Indonesian islands of Ceram and Aru and in northwestern Irian Jaya. *A. auriculiformis* occurs in Australia's Northern Territory and in some Indonesian islands off Irian Jaya as well as Queensland and PNG. *A. aulacocarpa* occupies a more extensive range including north western Western Australia, Northern Territory, Papua New Guinea and Indonesia, and its range extends south along the Queensland coast as far as New South Wales. The taxonomy of *A. aulacocarpa* is currently under revision and the populations with good potential for plantation forestry are restricted to southern New Guinea and north eastern Queensland (Thomson 1994).

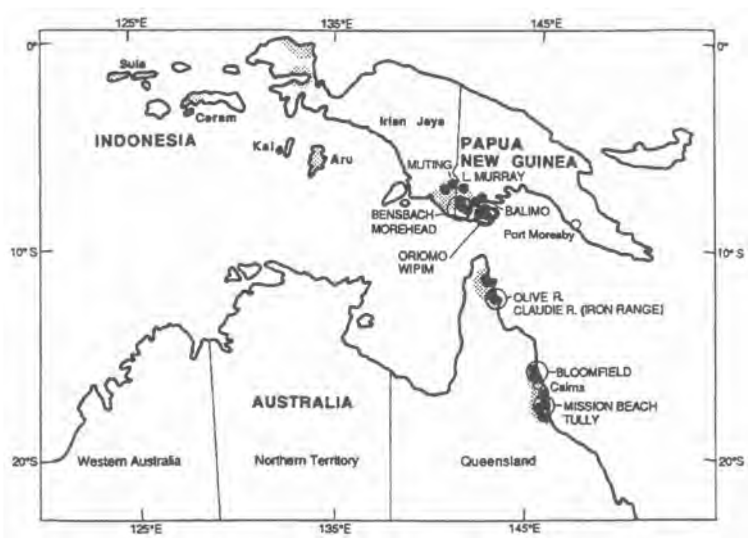

Fig 1. Map of the natural distribution of *Acacia mangium*

EXPERIMENTAL RESULTS

A. mangium grows extremely fast in the humid and seasonally dry tropics, producing up to 7.2m/y in height growth (14.4m in 2 years, Racz and Zakaria 1987), but more generally over 4m/y for the first 2-4 years, dropping to 2-2.5m/y after that (Lim 1987). MAI for diameter varies from 1.8cm/y to 7.4 cm/y. Many published volume production estimates are available from young research plantings (eg. Sim 1987, Turvey 1995, Otsamo *et al.* 1996) indicating volume production of 40 m^3 ha' per year, but there are few estimates of volume produced from large scale plantations at full rotation. Growth can often fall away after the first 3-4 years on shallow, infertile soils. MAI of much over 20 m^3 ha^{-1} on an operational scale over a full rotation would appear to be exceptional, requiring a combination of high-quality sites, best genetic material and good silviculture.

The current best estimates of the climatic range required for good growth of *A. mangium* (adapted from Booth 1996) are as shown below. These estimates have been determined by computer-based analysis of the climates throughout the species' natural range, together with analysis of climatic records from areas where the species is known to perform satisfactorily as an exotic.

Annual rainfall	1500-3000 mm
Length of dry season (consecutive months with less than 40 mm rainfall)	0-6 months
Mean annual temperature	22-30°C
Mean maximum temperature of the hottest month	30-40°C
Mean minimum temperature of the coldest month	9-24°C
Extreme minimum temperature	0°C

A. auriculiformis appears to be able to tolerate a somewhat longer dry season and lower annual rainfall, while *A. aulacocarpa* and *A. crassicarpa* have very similar requirements to *A. mangium*. Enthusiasm for growing tropical acacias is leading to their being planted in much drier conditions, leading to poor yields and complete failure in some cases. Strong wind is another important factor affecting success of plantations and species choice. *A. mangium* with its very heavy canopy and low density, low strength wood is the most susceptible species and is not suitable for planting in cyclone prone areas.

Species characteristics. In general *A. mangium* is usually the fastest-growing species of the four during the first few years, but on sandy, infertile sites, *A. crassicarpa* can grow as fast or faster (Sim 1991). *A. mangium* has the lowest wood density and *A. auriculiformis* the highest as judged from pilodyn measurements (Sim 1991) and during pulping trials (Clark *et al.* 1991, Kha 1996). *A. mangium* tolerates infertile, acid soils, whereas *A. auriculiformis* tolerates alkaline soils (Nikles and Griffin 1992). Although *A. mangium* grows very fast, it frequently forks. Stems of *A. auriculiformis* are very rarely straight whereas *A. aulacocarpa* frequently forms straight, single stems, but does not grow as fast as the other species. *A. crassicarpa* is susceptible to borers (although damage from the pin hole borer is not economically important Sim pers. comm. 1996) and to damage from wind although it does grow fast.

Some of the species readily form hybrids and *A. mangium* x *A. auriculiformis* has demonstrated superiority to the pure species in some circumstances (Pinso and Nasi 1992, Kha 1996).

The hybrid *A. mangium* x *A. auriculiformis* has shown promise for growth in Sabah where it grew 6 & 17% faster for height and 11 & 35% faster for diameter than *A. mangium* on two sites aged 11 & 7 years respectively (Lapongan 1987). In Vietnam (Kha 1996) the hybrid had twice the stem volume of *A. mangium* at 4.5 years and had significantly higher wood density, pulp yield and quality.

Improvement objectives. First, species must be correctly matched to site so that best growth rates can be obtained. Production objectives must be known - pulp, sawn timber, veneer and or fuelwood. In the first 1-2 generations, improvement programs have focussed on increasing stem volume and improving stem form (straight, single stems to improve recovery of solid wood products and reduce harvesting costs for pulpwood). Wood quality (density and pulp yield for pulpwood, and appearance, strength and freedom from defects for solid wood products) will become important objectives in advanced breeding programs.

Provenance results. Provenance trials of *A. mangium* have shown that on most sites the provenances from PNG and south eastern Irian Jaya are the most productive in terms of wood volume (Harwood and Williams 1992, Otsamo *et al.* 1996). Three-year results of an international series of provenance trials of *A. auriculiformis* are less clear-cut (Awang *et al.* 1995). However, in trials in northern Australia, Vietnam, Malaysia and India, the general trend has been for PNG and Queensland provenances to produce the greatest volume, and Queensland provenances to display the best stem form (single, straight main stems). Very poor performance of land races from India and SE Asia has been a feature of some trials (Bulgannawar and Math 1991). Northern Territory provenances have usually displayed slow growth and poor stem form. PNG provenances of *A. crassicarpa* and *A. aulacocarpa* have been found to have superior growth rates than those from Queensland in most provenance trials (Thomson 1994).

An intriguing finding is that these growth patterns for provenance regions of *A. mangium* seems to follow levels of genetic diversity at RFLP loci (Butcher *et al* 1996). Seedlots from the Indonesian island of Ceram and from Sidei in northwestern Irian Jaya had the lowest diversity; provenances from PNG were more diverse than Cape York provenances in turn more diverse than provenances further south in Queensland (Butcher *et al.* 1996).

Seed collection. Seed from the best natural provenances in New Guinea and far north Queensland is expensive to collect and sells at a high price on the international market. Seed production is prolific. Seed orchards of *A. mangium* in northern Queensland have produced annual crops of over 50 kg of seed per hectare from age 5 years on. This makes establishment of seed production areas and seed orchards an early priority in any planting program and improvement strategy.

INTRODUCTIONS

Acacia auriculiformis has been planted as a street tree in southeast Asia for many years and has been well-known as an ornamental in Thailand since 1935 (Pinyopusarerk 1987). The provenances involved in the initial introductions are not known. Australian acacias were introduced to China in the 1950s, beginning with the temperate species *A. mearnsii*. The tropical species were introduced in the 1960s beginning with *A. auriculiformis* to Guangzhou in 1961 (Pan and Yang 1987). This species is still the most widely planted tropical acacia in the country (50,000 ha plus 3000km roadside plantings) (Wang and Fang 1991). Other tropical species such as *A. mangium* and *A. crassicarpa* were first introduced in 1979.

Acacia mangium was introduced to Sabah (East Malaysia) in 1966 as seed from a single mother tree from the Mission Beach, Queensland provenance, for use in firebreaks (Sim 1987). Successive plantations derived from the original introduction have shown progressive decline in vigour (Sim 1984), most probably the result of buildup of inbreeding depression from this narrow genetic base. Seed from seed orchards derived from this initial introduction performs poorly relative to superior natural provenances such as Oriomo, Papua New Guinea and Claudie River, far north Queensland (Turvey 1995). Seed production areas at Subanjeriji, south Sumatra, were established in 1979 from Julatten, Mossman and Cassowary, inferior provenances in the south of the species range in Queensland. Seed from Subanjeriji has also performed poorly relative to Oriomo and Claudie River (Turvey 1995, Otsamo *et al.* 1996).

Beginning in the late 1980s, large-scale collections of *A. mangium* from many hundreds of trees in have been made in New Guinea and the Claudie River area in Queensland, and these collections have provided much of the seed for recent plantation establishment, providing growers with an excellent broad genetic base from the best provenances for selection. Many organisations have now established their own seed production areas and seedling seed orchards based on these superior provenances, and these stands are starting to yield seed. Similar bulk collections of *A. auriculiformis* and *A. crassicarpa* have also been used for plantation establishment on a smaller scale.

Research organisations and commercial growers in several countries have established genetic base populations in the form of seedling seed orchards, using hundreds of individual-tree seedlots of known natural provenance origin collected by the CSIRO Australian Tree Seed Centre.

WHAT IS IT USED FOR

As a native-forest species, none of the species is much used. In PNG, for example, villagers prefer other species for poles and commercial timber-getters are more interested in other hardwoods. However, most of the new plantations in southeast Asia are to be used for pulp and paper. There are now 15 pulp mills in Indonesia with a capacity of 2m tonnes per year and there are plans to build a further 6 mills by the end of 1999 with a further capacity of 1.9m tonnes. In Sabah, the current SFI mill operates with a capacity of 150k tonnes per year and there are plans for 2 mills in Sarawak with a capacity of 2m tonnes/year. Although these mills do not operate exclusively on plantation acacias, they illustrate the capacity of the region to process plantation-grown wood into pulp. Some of the organisations planting acacias are planning to produce timber which can be used for solid wood products and veneer, with the residues being used for pulp. In Malaysia and Indonesia, very large expansions of the plantation resource are planned for the year 2010. In Indonesia plantations are planned to be more than three times as large by 2010,whereas in Malaysia, a ten-fold expansion is planned.

Acacia mangium is a light hardwood and has properties comparable with other tropical hardwoods such as *Shorea* species. It has an attractive appearance and makes good furniture, but the prevalence of knots reduces quality (Razali 1993). In Peninsular Malaysia, *A. mangium* was planted in the Compensatory Planting Program for production of timber. Heartrot and soft knots greatly reduced the recovery rates of sawn timber in these plantations (Ho Kam Seng and Sim Heok Choh 1994). *A. auriculiformis* has higher density wood which is suitable for furniture making and other solid wood applications (Pinyopusarerk 1990). The interspecific hybrid between these two species has wood of intermediate density with excellent pulping properties (Kha 1996). Acacias produce fuelwood of acceptable quality, and are used for this purpose in rural areas of many countries including India, Thailand and Vietnam.

BREEDING STRATEGIES

Breeding strategies in outcrossing species are usually a compromise between reducing genetic variability to maximise gain and increasing genetic variability to retain flexibility. Gain is maximised in the short term when the "best" genotype is selected and propagated in a non-varying environment. As environments (both growing and marketing) change, the definition of "best" also changes and so some flexibility is required. Breeding and selection in a population with too little genetic variability frequently leads to inbreeding depression. Hence some level of genetic variability is required to avoid too much inbreeding and to provide for genetic recombination each breeding cycle. Too much genetic variability leads to maladaptation and lack of genetic progress because there is too little genetic selection.

In devising a breeding strategy, we must make use of features of the biology to optimise the gains. These were summarised by Matheson and Sim (1992):

- Prolific in numbers of seeds produced (pioneer species) (more than 100,000 seeds per year per tree)
- Flowers early in life-cycle (seed at about 3 years of age)
- Difficult to control-pollinate
- Difficult to vegetatively propagate on large scale from adult stock
- Can vegetatively propagate on small scale (marcots & cuttings)
- Tissue culture only from embryos
- Can make cuttings of young seedlings
- Hybrid A. mangium x A. auriculiformis seems promising
- Actual status of natural hybrid trees unknown, so it would be unwise to base a breeding program on them.

Matheson and Sim (1992) devised a breeding strategy for the main four tropical acacias to be applied in Sabah which made use of these features as far as was possible. Because controlled pollination is very difficult in these acacias, complete control of pedigree is impractical within a breeding program for these species. Although bulking up small numbers of CP seed through stem cuttings is possible, it takes time; about 1 year to make enough cuttings for 100 ha. The occurrence of malformations following tissue culture (Dares 1992) mean that tissue culture may not be advisable. Early and prolific flowering mean that gain may be more effectively achieved through open-pollination and quick turn over of generations. It is also much simpler and requires much less infrastructure. The strategy published by Matheson and Sim (1992) was therefore based on open-pollination, but made allowance for propagation by stem cuttings of small numbers of control-pollinated seed.

The strategy involved two parallel population combining features of multiple population breeding (Namkoong *et al* 1980) in which populations are subject to slightly different selection and subline breeding in which sublines are separately maintained (without crossing) but within which inbreeding is allowed to increase (Matheson and Brown 1983). The parallel populations could be different lines of the same species for single species breeding or they could be different species where the hybrid shows promise (eg *A. mangium* x *A. auriculiformis).* The scheme is shown in Fig n and begins with 50 plus tree selected for each population. The 10 best of these are marcotted each 10 times to provide material for a clonal seed orchard. The seed orchard is constructed by pairs of trees (one from each population) being planted so close to one another that their crowns intermingle. Because selfing rates are low, most of the seed from these crowns will be from crosses between the two parents. Individuals to make up each pair should be selected so they flower at the same time. From the 50 selections, 30 OP seedlings are selected and 5 cuttings taken from each one to form a clonal progeny trial. These trials are measured and then culled based on the measurements before flowering. The best 50 individuals are then selected to regenerate the population and 30 seeds collected from each, the best 10 trees are marcotted to form clonal seed orchards as before. Selection can be carried out using more than one individual from better families, only one from the poorer families (Lindgren and Matheson 1986). The culled trials can then be used as seed production areas whose seed can be compared with seed from the clonal hybrid orchards. As controlled pollination techniques improve, they can be used to cross populations instead of using the hybrid orchards. New material can be infused at the clonal progeny test stage. Each generation of breeding in this way can be completed in about 5 years with a normal rotation length for pulp and paper of about 8 years.

Another strategy has been to establish seedling seed orchards (S SO) made up of family-identified (usually) seedlots derived from collections from natural provenances. (Harwood *et al.* 1994). These orchards perform the dual purpose of trials for identifying superior provenances and families and are then thinned initially to a single tree in each plot. Further thinning by provenance and family is possible. However, neighbourhood inbreeding in natural stands and differential amounts of selfing among families mean that selection should not be too intense or too stringent. Seedling seed orchards of *A. mangium*, *A. aulacocarpa*, *A. auriculiformis* and *A. crassicarpa* were established in northern Australia over the period 1989-1991 (Harwood *et al.* 1994). A seedling seed orchard of *A. auriculiformis* was established by the Royal Forest Department, Thailand in 1989, and two second-generation SSOs of this species were planted in Thailand in 1994. More recently, seedling seed orchards and seed production areas of some or all of the four species, using adequate genetic bases of superior provenances, have been established in India, the Philippines, Vietnam and Indonesia, by private companies and government agencies. The FORTIP program, with technical support from ATSC, has collaborated with government research agencies to establish many of these orchards.

Pests & diseases Only a few insect pests are of major importance - root feeders (eg termites), branch and stem borers (*Sinoxylon* spp. and the red coffee borer (Chaweewan Hutacharern 1993).

The most important to date is heart rot, first observed in 1981 in Sabah, then in Peninsular Malaysia. It is most prevalent in trees more than 4 years old. It seems to be associated with branch stubs from self- or artificial pruning (Lee 1993). Although so serious in Peninsular Malaysia that planting has been suspended, it is not thought to be a threat in Sabah. This relates to the rotation length and end use applications: *A. mangium* is grown for timber in Peninsular Malaysia with a rotation length of around 15 years, but for pulp in Sabah with a rotation length about 8 years. *A. auriculiformis* and the hybrid seem to be less susceptible than *A. mangium* and the incidence of the disease seems lower in Sabah than Peninsular Malaysia. Heart rot does not seem to affect the quality of pulp or paper (Sim Boon Liang, pers. comm.)

A range of fungal diseases, including leaf spots, gall rusts, shoot blights, stem cankers, heart rot, and root rots may affect the future productivity of tropical acacia plantations (Old *et al.* 1996). Some fungal diseases may be more prevalent in lowland equatorial south east Asia, where high humidity and rainfall occur throughout the year, than in most of the natural range, where there is a distinct dry season.

CONCLUSION

The four tropical acacias discussed here are very promising species for the humid tropics, particularly Asia and Southeast Asia. They grow very fast, particularly so when young, yet form timber of high density and are suitable for use as pulp. Large areas of plantations are currently being established, and plans are to extend these plantings considerably. Apart from the heart rot which has affected plantations in Peninsular Malaysia, these species have so far remained remarkably free of pests and diseases. Principal traits for improvement are bole length (to reduce forking), stem straightness and branching. The hybrid between *A. mangium* and *A. auriculiformis* shows great promise.