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Sandalwood research – *Santalum spicatum*

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Early research into *S. spicatum* silviculture occurred in 1895, when *S. spicatum* was planted in bush land, near Pingelly, Western Australia (Herbert, 1925). Since 1974, the former Forests Department, the Department of Conservation and Land Management, Forest Products Commission (FPC), Curtin University of Technology, Murdoch University, the University of Western Australia and the Department of Agriculture have conducted research into various aspects of *S. spicatum* ecology, parasitism, silviculture and oil composition. Four main areas of *S. spicatum* research are (1) recruitment and regeneration, (2) plantation establishment, (3) oil composition, and (4) genetic variation. This report outlines research conducted into these four important topics.

Recruitment and regeneration

At present, natural recruitment of *S. spicatum* is generally low in the semi-arid regions (mean annual rainfall < 250 mm) of Western Australia. *S. spicatum* inventory from 1980-84 show that the proportion of seedlings with stem diameters below 25 mm (at 150 mm above the ground) was low in the Murchison and Goldfields regions (Kealley, 1991). In 1996-97, these findings were confirmed by a detailed assessment on 1353 *S. spicatum* near Paynes Find and Menzies (Brand, 1999; Brand 2000). Near Paynes Find, less than 2 % of the *S. spicatum* surveyed had stem diameters less than 60 mm. In these semi-arid regions, *S. spicatum* stem diameters increase only 1-2 mm yr^{-1} (Loneragan, 1990; Brand, 2000). Therefore, there has been very little successful recruitment in this region for 30-60 years. Recruitment levels were higher near Menzies, with 26-34 % of *S. spicatum* with stem diameters less than 60 mm.

Broad scale surveys, estimating stem diameter from vehicles also show that there is a lack of *S. spicatum* recruitment on many pastoral leases. During 1995-97, Glenorn, Minara, Tarmoola and Yakabindie stations were surveyed for *S. spicatum* density and size structure (Brand and Jones, 2002). Natural recruitment was low on these stations, with less than 1.5 % of *S. spicatum* having stem diameters below 25 mm, and 7.9 % with stem diameters 25-74 mm. This pattern of low recruitment was present on seven different land surface types: hills and ridges; breakaways; erosional surfaces; wash plains; plains; saline plains; and sand plains.

The lack of recruitment in these pastoral regions appears to be due to poor seed dispersal (Brand, 2000) and grazing by feral and domestic herbivores (Loneragan, 1990; Brand, 2000). To determine methods to improve *S. spicatum* recruitment in the rangelands, a number of trials have been set up on de-stocked and stocked pastoral leases. These trials have shown that direct seeding is an effective method to promote recruitment. Besides recruitment of seedlings, trials have also examined the effectiveness of regenerating mature *S. spicatum* trees after harvesting through stem coppice.

Direct seeding

Loneragan (1990) examined the effect of grazing on seedling survival on two stations (Gindalbie and Jeedamya) managed for sheep grazing, and two reserves (Calooli and Bullock Holes) in the Goldfields. In 1974, 1600 *S. spicatum* seeds were planted within fenced and unfenced plots on each of these stations and reserves. Each plot contained natural vegetation and the seeds were sown in a grid pattern. At age three years, the percentage of live seedlings was only 2.9 % of the seeds sown, and was significantly higher in the fenced plots (4.7 %) than the unfenced plots (1.1 %).

At Ninghan station, a trial was established to examine the effects of management regime and host species on *S. spicatum* recruitment. Recruitment success was compared between three establishment treatments: beneath parent trees (natural); seeds sown at harvesting spots; and seeds sown near host trees (Brand, 2000). Due to its parasitic nature (Hewson and George, 1984), *S. spicatum* seeds were planted near four separate host species: *Acacia burkittii*, *A. ramulosa*, *A. tetragonophylla* and *Hakea recurva*. On Ninghan, sheep and goats were present and their influence on seedling survival was also compared between fenced and unfenced treatments. In June 1996, over 10 000 seeds were planted and germination was 23-39 % in seed enriched treatments. At age three years, mean survival of *S. spicatum* seedlings was 25 % near host trees, significantly greater than beneath parent trees (0 %) or at harvesting spots (2 %). Within the host seed enriched treatment, seedling survival was also greater in the fenced treatment (30 %) than the unfenced treatment (20 %). This equates to 8-12 % of seeds planted near host plants producing live seedlings at age three years.

The results from Ninghan showed that natural recruitment of *S. spicatum* was very poor, even when grazing was excluded. It appears that moving *S. spicatum* seeds away from parent trees and planting them near suitable host species protected from grazing dramatically improves seedling survival. In the past, small native marsupials, such as woylies (*Bettongia penicillata*), may have cashed *S. spicatum* seeds away from parent trees (Havel, 1993). The woylie disappeared from central Western Australia over 50 years ago (Burbidge *et al.*, 1988).

In 1997, a similar trial was established on Goongarrie station to determine the influence of four landforms and seven potential host species on *S. spicatum* establishment. *S. spicatum* seeds were planted near *Acacia aneura*, *A. burkittii*, *A. coolgardiensis* subsp. *coolgardiensis*, *A. hemiteles*, *A. ramulosa*, *A. tetragonophylla* and *Senna artemisioides* subsp. *filifolia* (Brand, 2002). Eight seeds were planted near 480 host plants – total 3840 seeds. These host plants were all unfenced and on four separate landforms: hills and ridges, granite, calcareous red earths and red sand plains. In November 1997, mean germination was 22.1 %, and at age three years (2000), mean survival was 27.1 %. Mean survival was highest near *A. burkittii* (56 %), and lowest near *A. ramulosa* (10 %) and *A. tetragonophylla* (10 %). Mean seedling heights ranged from 70 cm to 110 cm, and seedling diameters (at 150 mm) were 5-10 mm. There was little evidence of grazing on Goongarrie, with less than 1 % of seedlings having shoots removed each year. Goats have not been observed during trial visits.

An unpublished study also examined the influence of different host species, landforms and grazing on *S. spicatum* establishment on two adjoining stations: Burnerbinmah and Thundelarra, near Paynes Find. Burnerbinmah was de-stocked of sheep in 1995, while Thundelarra was managed for grazing. On Burnerbinmah, *S. spicatum* seeds were planted near *Acacia aneura*, *A. burkittii*, *A. tetragonophylla*, *A. grasbyii* and *Scaevola spinescens*. In March 1996, 2560 seeds were sown in unfenced plots on Burnerbinmah, and 328 seeds were sown in fenced plots on both stations. Germination was similar between plots, ranging from 44 % to 54 %. At age five years (2001), mean survival was 19.0 % in fenced plots and 10.9 % in unfenced plots. Mean seedling heights were also greater in fenced plots (78 cm) than unfenced plots (45 cm). Although Burnerbinmah was de-stocked of sheep, goats were observed frequently on this station and the *S. spicatum* seedlings showed signs of grazing.

On Burnerbinmah, 318 mature *S. spicatum* trees growing naturally were also measured in 1996 (Brand, 1999) to monitor recruitment of seedlings. During 1996-

1999, 86 new *S. spicatum* seedlings were recorded beneath parent trees, with none observed away from the parent. By 2001, all of these seedlings had died. Some of the seedlings showed signs of grazing, but many appeared to have died from drought stress beneath the parent. In contrast, seedling survival was far greater in the direct seeding trials near host species. These results agree with the findings at Ninghan, that *S. spicatum* seedling survival is greater when planted near a host tree than natural recruitment (Brand, 2000). In 2001, five of the parent trees had died at Burnerbinmah and another two appeared to be very sick with little live tissue on their stems. Therefore, the natural population of *S. spicatum* is declining on Burnerbinmah, even with no sheep present for six years.

These trials indicate that direct seeding *S. spicatum* near suitable host species and excluding grazing is an effective method to improve recruitment. Direct seeding *S. spicatum* is now incorporated into the harvesting contract. After harvesting, contractors are required to plant *S. spicatum* seeds near suitable host plants, especially *Acacia* species. The FPC is monitoring the effectiveness of this technique in pastoral regions.

Coppicing trials

S. spicatum harvesters generally remove the entire tree because the roots, butt, stem and branches contain valuable oils. To promote conservation, it could be encouraged to harvest only the stem and branches and let the trees regenerate at the base through stem coppice. However, in the Goldfields, stem coppice survival of *S. spicatum* after harvesting is generally low due to grazing and drought. In 1975-76, 64 *S. spicatum* trees were cut at ground level on Calooli Sandalwood Reserve and Gindalbie station (Loneragan, 1990). Four of the cut stems produced coppice, but none of the coppice survived.

However, at Nanga station near Shark Bay, *S. spicatum* stem coppice after harvesting was more common. In this region, the *S. spicatum* trees typically grow in dense *Acacia* shrub land and on deep red sand dunes, making it difficult to harvest with a vehicle. Instead, the trees were cut near the base of the stem with a chainsaw, and trials have shown that stem coppice was successful. In 1988, 71 mature *S. spicatum* growing on red sand dunes at Nanga were cut near the base and 58 % of these had live coppice at age three years (Doronila and Fox, 1991). In another trial, 200 naturally occurring *S. spicatum* trees at Nanga were harvested by cutting the stem at 150 mm above the base in August-December 1988 (Ryan and Brand, 2002). At age 12 years (November 2000), 40.8 % of the trees were alive, with a mean height of 1.7 m and a mean stem diameter of 28 mm (at 150 mm). Flowering occurred at age four years, and 15 % of the coppice stems produced mature fruit at age 12 years.

Although the coppice survival at Nanga was encouraging, there was a 59 % decrease in tree numbers 12 years after harvesting. The trees were also growing on deep red sand dunes near the coast, which is not typical of the environments where *S. spicatum* grows in the arid interior. Therefore, this coppicing rate may be unique to Shark Bay.

Plantation establishment

Since the 1970s, research has been conducted to establish *S. spicatum* in commercial tree farm systems on farmland areas with annual rainfall of 400-600 mm. Early attempts to grow *S. spicatum* with a host in plantations were problematic. In 1978, Loneragan (1990) grew *S. spicatum* seedlings in pots with a pot host - *Acacia acuminata*. When the seedlings were age 4-5 months, they were planted in the field at Dryandra, near Narrogin. At age two years, seedling survival was only 2 %. This trial was repeated in 1979, using another pot host – *Acacia aneura*. However, *S. spicatum* seedling survival was again only 2 % at age two years. In 1981, (Wijesuriya and Fox, 1988) planted *S. spicatum* seedlings, germinants and seeds in the field containing natural *A. acuminata* at Dryandra. Mean survival was 16 %, and was similar between treatments. During 1982-84, Fox and Wijesuriya (1985) also attempted to establish *S. spicatum* by planting seedlings on farmland near a range of potential host species, including *A. acuminata*, *A. saligna*, *A. lasiocalyx*, *Eucalyptus wandoo*, *E. loxophleba*, *E. camaldulensis* and *E. decipiens*. However, survival rates were only 2-14 % at age one year. Fox and Wijesuriya (1985) recommended that direct seeding *S. spicatum* may be just as effective and more economical than planting seedlings.

In 1987, a *S. spicatum* establishment trial was established at Northampton using more of a plantation design (Brand *et al.*, 1999a). A site approximately 0.8 ha was scalped to remove weeds and 14 lines were ripped 4.5 m apart. Young *A. acuminata* seedlings were planted at 4 m intervals (556 stems ha^{-1}) along each ripped line. At host age one year (1988), *S. spicatum* seeds were planted near host seedlings in eight of the lines. The following year (1989), S. spicatum seeds were sown near hosts on the remaining lines. At age 8-9 years, mean *S. spicatum* survival was 50-87 %. Mean stem diameters (at 150 mm above the ground) were increasing 4-7 mm yr^{-1} between age four and nine years. However, host mortality was high after age seven years and *S. spicatum* growth slowed. Host survival appeared to be related to the age of the host when the parasite was introduced and the parasite-to-host ratio. At host age 10 years, host survival was much lower when the parasite was introduced at host age one year (37 %) than at host age two years (84 %). At Northampton, the *S. spicatum* were planted next to the host trees at a ratio of 1:1 which may have also reduced survival.

The encouraging results from Northampton prompted more research to improve *S. spicatum* performance in plantations. Some of the areas investigated were (1) host species, (2) parasite–to-host ratios, (3) fruit production, and (4) provenance trials.

Host species

Near Katanning, a host trial was established to compare *S. spicatum* survival and growth near three different potential host species: *Acacia acuminata*, *Allocasuarina huegeliana* and *Eucalyptus loxophleba* subsp. *loxophleba* (Brand *et al.*, 2000). In 1991, the host seedlings were planted at 4 m intervals along rows spaced 4 m apart (625 stems ha^{-1}). At host age five years (1996), *S. spicatum* seeds were sown near each host plant (625 stems ha^{-1}). At age three years (1999), *S. spicatum* survival near *A. acuminata* was 86 %, and was significantly greater than near *A. huegeliana* (29 %) and *E. loxophleba* subsp. *loxophleba* (0 %). At the same age, mean *S. spicatum* stem diameter near *A. acuminata* (26 mm) was two times greater than those near *A. huegeliana* (13 mm). *S. spicatum* growing near *A. acuminata* also had higher concentrations of N and K and a higher K:Ca ratio than those near *A. huegeliana*.

Having shown that *Acacia acuminata* was a preferred host, another trial was established to examine *S. spicatum* performance with some other *Acacia* species: *A. acuminata*, *A. microbotrya*, *A. saligna* and *A. hemiteles* (Brand, 2002). The host seedlings were planted in June-July 1998 at two separate sites: Narrogin and Dandaragan. The hosts were planted at 3 m intervals along rows spaced 4 m apart (832 stems ha^{-1}). In April 1999, *S. spicatum* seeds were planted near each host on alternate rows (416 stems ha^{-1}). At age two years (2001), mean survival of *S. spicatum* was higher near *A. saligna* (91-92 %) than near *A. hemiteles* (48-58 %), at both Narrogin and Dandaragan. Mean survival of *S. spicatum* near *A. acuminata* and *A. microbotrya* was 62-84 %. *S. spicatum* seedlings near *A. saligna* were also the tallest (144-170 cm) and had the largest stem diameters (29-33 mm). *A. saligna* appears to be a good initial host for *S. spicatum*. However this species can be short lived (5-10 years) and will need to be planted with a long-term host (e.g. *A. acuminata*) to effectively grow *S. spicatum* through to commercial size.

Parasite-to-host ratio

Planting *S. spicatum* near *A. acuminata* seedlings at a 1:1 ratio appeared to reduce host survival after age seven years at Northampton. Increasing the number of host trees for each *S. spicatum* may improve the performance of both parasite and host. To examine the effect of parasite-to-host ratio, a trial was established near Narrogin. In July 1997, a 6 ha trial site was planted with four host species: *Acacia aneura*, *A. acuminata*, *A. microbotrya* and *Allocasuarina huegeliana* (Brand, 2002). The host species were planted 4 m by 4 m (625 stems ha^{-1}) in separate species plots. At host age two years (1999), *S. spicatum* seeds were planted at three parasite-to-host ratios: no *S. spicatum* per host, 1:2 and 1:1.

At age two years (2001), mean survival of *S. spicatum* was similar between host treatments (90-99 %). However, mean *S. spicatum* stem diameters were far greater near *A. aneura* (24 mm) and *A. acuminata* (19 mm) than near *A. microbotrya* (10 mm) and *Allocasuarina huegeliana* (10 mm). At this early stage, *S. spicatum* and host species did not appear to be affected by parasite-to-host ratio, but an effect is likely to be observed at later years.

Fruit production

S. spicatum flower between January and April and produce mature fruits between July and October (Barrett, 1987). The fruit consists of a brown leather-like exocarp that encloses a hard smooth nut of approximately 2 cm in diameter. Within the nut is a white edible kernel, similar in composition to almonds, peanuts and macadamias. It contains approximately 60 % fat, 18 % protein and 16 % carbohydrate (Flanagan and Barrett, 1993). At Curtin University, individual *S. spicatum* trees have produced over 1 kg of seeds at age six years (Barrett, 1987). *S. spicatum* seeds are currently valued at \$30-50 (Aus) kg^{-1}, and are mainly sold for tree growing rather than consumption. The nut crop from plantations could provide a supplementary income while waiting for the trees to reach commercial size.

Provenance trials

The commercial value of *S. spicatum* grown in plantations may be improved through selection. *S. spicatum* displays phenotypic and genotypic variation throughout its natural distribution (Fox and Brand, 1993; Byrne, 2001), and it may be possible to identify individuals or provenances with desirable characteristics, such as fast growth or high oil content. To examine the level of variation, *S. spicatum* seeds are being collected from different locations and will be planted together in provenance trials in the Wheatbelt.

Besides *S. spicatum*, provenance trials are also being established for one of the preferred host species - *A. acuminata*. The *A. acuminata* group is variable and consists of seven taxa (Maslin *et al.*, 1999): *A. acuminata* (typical); *A. acuminata* (narrow phyllode); *A. acuminata* (small seed); *A. burkittii*; *A. oldfieldii*; *A. acuminata/burkittii* (variant 1); and *A. acuminata/burkittii* (variant 2). Within this group it may be possible to identify certain types that are superior hosts and would lead to improved *S. spicatum* performance.

In October-December 1998, seeds were collected from individual parent trees from these seven taxa. Seedlings were grown from 84 separate parent trees and were planted at Morawa and Dowerin in July 2000. *S. spicatum* seeds will be direct seeded near these host seedlings in May 2002.

Oil composition

The fragrant oils of *Santalum* species are contained within the heartwood, and the average oil content is higher in *S. album* (6-7 %) than *S. spicatum* (2 %; Applegate *et al.*, 1990). Within the oil, the main compounds responsible for the distinct sandalwood fragrance are α-santalol and β-santalol (Adams, *et al.*, 1975). Some of the other major compounds within *S. spicatum* oil are 2(E), 6(E)-farnesol; epi-α-bisabolol; and nuciferol (Piggott, *et al.*, 1997). The oil can be extracted using different techniques, including steam distillation, solvent extraction, and supercritical fluid extraction (SFE). A higher percentage of oil is generally obtained using solvent and SFE (Piggott *et. al.*, 1997).

In mature *S. spicatum* trees from natural stands, oil percentage is generally higher near the base (large roots, buttwood and large stems) than in the branches and small roots (Piggott *et. al.*, 1997; Brand *et al.*, 1999b; Moretta *et. al.*, 2001). Within the oil, the proportion of α- and β-santalol is also higher near the base of the tree, whereas the proportion of epi-α-bisabolol and farnesol is higher in the branches (Piggott *et. al.*, 1997; Moretta *et. al.*, 2001).

In 1998, oil content and composition was determined in 12 *S. spicatum* trees (age 10 years) growing in a plantation, at Northampton (Brand *et al.*, 2001). Core samples were taken at 15 cm and 25 cm above the ground, and the oil was extracted using supercritical fluid extraction (SFE), with carbon dioxide as the extraction fluid. Total oil content at 15-25 cm above the ground was 2.3-2.6 %, which is comparable to that from natural stands. However, the average oil content further up the stems would have been much lower. The oil contained fragrant compounds, with 16.7-21.1 % α- and β-santalol. In May 2000 (age 11-12 years), 136 *S. spicatum* trees were harvested at the trial site and de-barked to obtain the commercial timber. The mean weight from each tree was approximately 3.8 kg. The stems were graded as small green logs with a value of $4 (Aus) kg^{-1} (Jones, 2001a). Mature trees with stem diameters above 127 mm, have an average value of $6 (Aus) kg^{-1} (Jones, 2001b). These results show that *S. spicatum* trees grown in plantations can produce valuable heartwood and aromatic oils at a relatively young age. However, heartwood and oil formation require time, and a greater financial return may be achieved by waiting until the trees are age 20 years.

Genetic variation

Fox and Brand (1993) found that *S. spicatum* populations from drier inland regions had smaller seeds, smaller leaves and greater leaf length/width ratios than populations nearer to the coast. These differences were believed to be adaptive features related to water conservation in drier inland regions. These observed differences may also be related to genetic differentiation within the species. An appreciation of the genetic diversity within *S. spicatum* may assist in selecting superior individuals or provenances for plantations in the Wheatbelt.

In 1999-2001, a detailed study was carried out to determine the level of genetic variation within and between *S. spicatum* populations in Western Australia (Byrne, 2001). Leaf material was collected from 10 *S. spicatum* trees from each of 23 separate populations that were distributed across a wide range in the Wheatbelt and pastoral regions (rangelands) of Western Australia. DNA analysis was conducted on these samples and the results showed that the mean estimates of total genetic diversity ($H_T = 0.233$) were moderate within *S. spicatum*. Genetic diversity was greater within populations ($H_S = 0.214$) than between populations ($G_{ST} = 8.3$ %).

The observed heterozygosity ($H_o = 0.216$) and the expected heterozygosity ($H_e = 0.220$) were similar within the *S. spicatum* populations, which indicates that the species is predominantly out-crossing. However, inbreeding may occur, but the inbred seeds may be selected against during juvenile stages of development.

Byrne (2001) states that the *S. spicatum* populations in the Wheatbelt have a lower level of diversity than the rangeland populations, but in the Wheatbelt there is a greater divergence between populations. This was possibly due to limited gene flow or due to the greater environmental gradient across the Wheatbelt compared to the rangelands. Future provenance trial plantings should aim to collect seeds from a wide range of populations in the Wheatbelt, especially in its southern distribution. These different provenance types should be planted together in a plantation to identify superior forms and determine whether the environment influences provenance form. Growing these different provenances together may also result in crossing. The seedlings produced from these crosses may have new genetic combinations that could result in superior growth.

Conclusions and recommendations

Recruitment

Lack of seedling recruitment appears to be the most significant threat to the survival of *S. spicatum* in the semi-arid pastoral regions of Western Australia. Recruitment failure appears to be due to a combination of poor seed dispersal and grazing by domestic and feral herbivores. *S. spicatum* seeds tend to germinate mainly beneath mature trees, where survival is very poor. Moving *S. spicatum* seeds away from parent trees and sowing them near suitable host species can dramatically improve recruitment. It has been hypothesized that woylies use to disperse and bury *S. spicatum* seeds away from parent trees (Havel, 1993). The woylies and other small marsupials are no longer present in central regions of Western Australia (Burbidge *et al.*, 1988). Future research should aim to examine the impact of small native marsupials on *S. spicatum* recruitment.

Grazing is a significant factor preventing successful recruitment. Grazing pressure can be reduced on stations by removing sheep and cattle, but controlling goats is more difficult. Burnerbinmah station was de-stocked to promote recruitment but goats continue to graze *S. spicatum* seedlings on this station. At age five years, seedling survival was two times greater in fenced plots than unfenced plots. In contrast, there has been little evidence of grazing on Goongarrie station, near Menzies. It appears that *S. spicatum* seedlings are more prone to grazing on some stations, especially in the northern half of the species distribution. Consequently, the seed enriching technique may not be as successful on these northern stations. On Burnerbinmah, the natural stands of *S. spicatum* have decreased by 1.5 % in only the last five years. In these northern regions, it is likely that *S. spicatum* populations will gradually disappear, unless active seed enrichment occurs and grazing pressure is reduced.

Since 2001, harvesters have been required to sow *S. spicatum* seeds near suitable host species. The FPC is monitoring the success of this seed enriching technique by contractors on all stations harvested. In addition to this broad scale monitoring, more *S. spicatum* direct seeding trials are being established in harvested regions of the Goldfields. These trials will examine the influence of harvesting, seed enrichment, host species, grazing and land forms on *S. spicatum* recruitment.

Plantation, oil composition and genetic variation research

Planting *S. spicatum* seeds near young *A. acuminata* seedlings has proven to be a successful and economic method to establish *S. spicatum* plantations. Encouraging survival rates of over 80 % at age 10 years have been achieved, with mean stem diameters increasing up to 7-9 mm yr^{-1} at age 1-7 years. *S. spicatum* trees grown in a plantation at Northampton were harvested at age 11-12 years and had a mean stem diameter of 72 mm and a mean weight of 3.8 kg. The stems contained fragrant santalol oils and were graded as small green logs with a value of \$4 (Aus) kg^{-1}. Although the trees are producing heartwood and oil at a relatively young age, a greater financial return may be achieved when the trees are age 20 years.

Farmers and private tree growing companies are currently using this technique to establish *S. spicatum* plantations in the 400-600 mm annual rainfall regions of the Wheatbelt. Current research is examining methods to further improve *S. spicatum* performance in plantations by examining the effects of different host species, host-to-parasite ratios and provenance trials. A host trial near Kwobrup showed that *A. acuminata* is a superior host than *Allocasuarina huegeliana*, and all *S. spicatum* seedlings died near *Eucalyptus loxophleba* subsp. *loxophleba*. *A. acuminata* appears to be the best long term host, but *A. saligna* may be an excellent initial host. *S. spicatum* growth rates have been very fast near *A. saligna* at age two years, but this host may only live 5-10 years. Future trials should examine the benefits of multi-host planting arrangements.

Improved performance may also be achieved by tree selection within both the preferred hosts (e.g. *A. acuminata*) and *S. spicatum*. The *A. acuminata* group is highly variable, consisting of seven taxa (Maslin *et al.*, 1999). Certain types or provenances of *A. acuminata* may perform better and provide more resources to the parasite, which may lead to improved *S. spicatum* performance. These different types of *A. acuminata* have been planted together in trials and there effect on *S. spicatum* survival and growth will be examined over the next 10-20 years.

The level of variation within and between *S. spicatum* populations was relatively low. However, there appears to be a distinction between *S. spicatum* growing in the rangeland regions and those in the southern Wheatbelt regions. Tree selection should concentrate mainly on these remnant southern populations that are growing in the region that is being chosen to establish plantations. Long-term research will be required to to identify superior *S. spicatum* that grow fast and produce high quality oil.

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