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Screening selected myrtaceous tree species for production of essential oils in northern Queensland

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Abstract. Trials to identify alternative cropping options to *Melaleuca alternifolia* for northern Queensland essential oil growers were established at Dimbulah and Innot Hot Springs in 2001. Seed sources of *Asteromyrtus symphyocarpa* (1,8-cineole form), *Eucalyptus staigeriana* (citral), *Melaleuca cajuputi* subsp. *cajuputi* (*trans*-nerolidol), *M. ericifolia* (*d*-linalool), *M. quinquenervia* (*trans*-nerolidol and viridiflorol forms) and *M. viridiflora* (methyl cinnamate) with potential to produce commercial foliar oils were evaluated. Information was gathered on their adaptability, growth and oil yields over 49 months and 52 months (two harvests) from planting at Dimbulah and Innot Hot Springs, respectively. Of the species and chemotypes evaluated, *M. quinquenervia* showed potential for commercial production of *trans*-nerolidol, a compound used in perfumery. It had a very high survival rate (96%) and yields could be expected to improve dramatically from the average 100 kg/ha per harvest achieved in these trials with further research into selection of seed source, control of insect damage and breeding for genetic improvement. *M. cajuputi* subsp. *cajuputi* gave a similar performance to *M. quinquenervia*. The rarity of the *trans*-nerolidol form of this species and remoteness of its natural occurrence are impediments to further planting and research. *E. staigeriana*, with second harvest yields of ~600 kg/ha, performed exceptionally well on both sites but potential for development is limited by the ready availability of competitively priced *E. staigeriana* oil produced in South America. Survival of *M. ericifolia* ranged from 62% to 82% at 32 months (second harvest) at Innot Hot Springs and was deemed a failure at Dimbulah with poor growth and low survival, raising a major question about the suitability of this species for cultivation in the seasonally dry tropics. Planting of this species on a wider scale in northern Queensland cannot be recommended until more is known about factors affecting its survival. *A. symphyocarpa* and *M. viridiflora* were too slow-growing to warrant further consideration as potential oil-producing species at this time.

Introduction

The decade 1990–2000 was a boom time for the Australian tea tree oil industry based largely on intensively managed plantations of *Melaleuca alternifolia* (Maiden & Betche) Cheel. In addition to northern New South Wales (NSW), where most production of this oil takes place, a thriving production base developed in northern Queensland (Qld), centred on Dimbulah, where the local growers co-operative had 60 members. This situation was to change dramatically after 2000 with over production of *M. alternifolia* oil forcing oil prices below the cost of production for many growers (Davis 2003). By 2001, many growers in northern Qld had replaced their tea tree plantations with other crops. Recently, increasing demand and slightly higher prices for oil have seen renewed interest in growing *M. alternifolia*. Diversification of the industry into additional oil-producing species, however, is seen as a safeguard against the calamity that occurred with tea tree in 2000.

A prerequisite to identifying potential candidate species for diversification was that they could be grown and harvested using the substantial infrastructure established for *M. alternifolia* (e.g. irrigation, harvesting equipment, distilleries, oil storages). The species and provenances selected needed to produce an oil that was in demand and commanded a price that might allow it to be viably produced in northern Qld, where relatively high labour and infrastructure costs exist. Furthermore, to optimise oil yield on a 'per hectare per year' basis and, therefore, the likely returns on investment, targeted species needed to possess a combination of desirable biological characteristics. Foremost among these were fast growth, good production of leaf biomass of high oil concentration, strong coppicing ability and adaptability to local conditions, especially high survival.

The trials reported here were established in 2001 to assess economically viable source species for essential oil production in the tropics with the aim of providing the industry in northern Qld with alternative cropping options to *M. alternifolia*.

Materials and methods

Selection of species and provenances

Nine seedlots (provenances) representing six species were selected for trial. Summary details of each seedlot including the oil types (chemotypes) targeted in provenance selection are given in Table 1. The *trans*-nerolidol form of *M. cajuputi* subsp.

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cajuputi included in these trials is rare (J. Brophy, pers. comm.) with seed coming from only one mother tree. This is in contrast to the other seedlots that are bulk collections from several trees. A brief description of the six species (ordered alphabetically by genus) and the rationale for their inclusion in the trials are given in Table 2.

Trial sites and establishment

Four trials were established on two sites in far north Qld to test the suitability of six species represented by nine provenances for commercial essential oil production. The tree species were planted at wider spacings than *M. ericifolia,* thus the need for two trials per site. Site 1 was ~11 km south-west of Dimbulah (17°12′S, 145°03′E; 470 m above mean sea level) and Site 2 was ~5 km south of Innot Hot Springs (17°39′S, 145°14′E; 640 m above mean sea level). Both experience a similar, seasonally dry, tropical climate with most precipitation (about 85%) falling in the five months from November to March. Estimated annual rainfall averages are 782 mm at Dimbulah and 863 mm at Innot Hot Springs (Houlder *et al*. 2000). Both sites are frost free.

Dimbulah was a mostly flat, irrigated site previously used for tobacco (1970–93) and tea tree oil production with nine commercial oil harvests between 1993 and 2000. The soil was a deep sandy clay loam (podzolic red earth) of neutral pH with quartz gravels throughout. Site preparation for planting consisted of preparing rip lines 1.2 m apart, discing three times between rows and applying the pre-emergent herbicide Treflan (trifluratin) before planting. The site at Innot Hot Springs was also a mostly flat, irrigated site previously used for small scale vegetable production over 10–20 years. The soil was a fertile, silty loam over friable light clay (red podzolic), moderately well drained and of slightly acidic to neutral pH. Site preparation was discing and rotary hoeing with pre-emergent herbicide (Dual and Goal) applied after planting.

Seedlots were provided by the CSIRO's Australian Tree Seed Centre and the seedlings were raised in a commercial nursery on the Atherton Tablelands. Seedlings were hand planted on 6–8 August (Dimbulah) and 18–19 September (Innot Hot Springs) 2001, after pegging out the sites to the appropriate experimental designs (see below). The spacing used differed slightly between sites and trials. At Dimbulah, row spacing was 1.2 m for both trials whereas spacing within rows was 0.66 m (12 626 plants per ha) within row for the tree species and 0.3 m (27 778 plants per ha) for *M. ericifolia*, whereas at Innot Hot Springs, spacing was 1 m between rows and 1.05 m (9524 plants per ha) within row for the tree species and 0.35 m (28 570 plants per ha) for *M. ericifolia*. Each of the four trials was surrounded by a single row buffer of the matching treatment to the adjacent trial plot. In addition, excess plants were machine planted into multiple long rows (100–150 m) of single treatments adjacent to the trials at both sites to allow broadacre yields to be more realistically estimated.

Frequent watering was applied during establishment but, thereafter, only when required. NPK (11 : 2 : 18) fertiliser (50 g/plant per application) was applied at each site in four applications per year. Weeds were controlled through application of Sprayseed (gramoxone) and Roundup (glyphosate) both applied twice per year. Treflan herbicide was applied in the first year at Innot Hot Springs, as was Lorsban (chlorpyrifos) to control cutworm among the *M. ericifolia*. Coreid bug caused substantial damage to the young flush growth of *Melaleuca* species between harvests at both sites and this undoubtedly had an adverse effect on the amount of leaf biomass and subsequent yield of oil at second harvest. At Dimbulah, Lanate was used to control the bug but it was only applied twice.

Experimental design and statistical analysis

The trials of tree species (six treatments) used row-column designs of 10 replicates and 5-tree line plots at Dimbulah and 6-tree line plots at Innot Hot Springs. The closer-spaced *M. ericifolia* trials employed row-column designs of 10 replicates of 8-tree line plots at Dimbulah and 10-tree line plots at Innot Hot Springs.

The software package DataPlus Version 3 (Williams *et al*. 2000) was used to pre-process the data and screen for outlying values, which were excluded from the various datasets. Subsequent statistical analyses were carried out on plot means using GENSTAT Version 5.3.2 (Payne *et al*. 1987).

Measurements and sampling

The trial of tree species at Dimbulah was assessed for height growth (cm) and survival (%) and partially sampled for leaf biomass and oil concentration determinations at 15.5 months after planting (Nov. 2002) and again 12 months later

Table 1. Species and provenances selected for trial at Dimbulah and Innot Hot Springs in northern Queensland showing treatment code, oil types targeted and seed source details

Species–chemotype code	Species	Oil type	Seed source
		Tree form established at wider spacings	
MQ-tn	*Melaleuca quinquenervia*	*Trans*-nerolidol	CSIRO seedlot no. 20424; Tuggerah Lake, NSW
MQ-v	*Melaleuca quinquenervia*	Viridiflorol	CSIRO seedlot no. 20459; Sydney (planted), NSW
MC-tn	*Melaleuca cajuputi*	*Trans*-nerolidol	CSIRO seedlot no. 19570; Elizabeth Downs, NT
MV-mc	*Melaleuca viridiflora*	Methyl cinnamate	CSIRO seedlot no. 20001; Lakeland Downs, Qld
AS-c	*Asteromyrtus symphyocarpa*	1,8-cineole	CSIRO seedlot no. 14150; Weipa, Qld
ES-ls	*Eucalyptus staigeriana*	Lemon-type (citral and limonene prominent)	CSIRO seedlot no. 17954; Cooktown, Qld
		M. ericifolia trial established at close spacings	
ME1-dl	*Melaleuca ericifolia*	*d*-Linalool	CSIRO seedlot no. 20425; Bateau Bay, NSW
ME2-dl	*Melaleuca ericifolia*	*d*-Linalool	CSIRO seedlot no. 20282; Coopernook, NSW
ME3-dl	*Melaleuca ericifolia*	*d*-Linalool	CSIRO seedlot no. 20332; Berry, NSW

Table 2. Brief description of the six species (ordered alphabetically by genus) and the rationale for their inclusion in the northern Queensland trials

Species (and common name)	Habit and distribution	Oil of commercial potential	Comments
Asteromyrtus symphyocarpa (F. Muell.) Craven (syn. *Melaleuca symphyocarpa*) (liniment tree)	A multi-stemmed shrub or small tree adapted to infertile and periodically waterlogged soils of northern Qld and the 'Top End' of the NT. It also extends to southern New Guinea (Turnbull 1986; Craven 1988).	Liniment tree has foliar oils rich in the terpene ether 1,8-cineole. Oils where 1,8-cineole is 70% or more of total oil are especially useful for treating respiratory ailments, but also find use in a wide range of personal care and household products (Coppen 2002).	This species is a source of 1,8-cineole in Papua New Guinea. However, it was considered only an outside chance for commercial oil production in northern Australia because of competition from much higher yielding *Eucalyptus* species.
Eucalyptus staigeriana F. Muell. ex Bailey (lemon-scented ironbark)	A small to medium-sized tree of the granite or sandstone hills of Cape York Peninsula, Qld at latitude 16–17°S (Brooker and Kleinig 2004).	The whole oil is sought for its lemony fragrance in perfumery and is purchased by smell alone. No single chemical predominates in the oil, although limonene and citral (neral and geranial) together account for ~50–60% of the total terpenes (Coppen 2002).	Price of bulk oil relative to alternative lemon-type oils (e.g. *Corymbia citriodora*) has dampened the market for *E. staigeriana* oil, despite it having an attractive odour. The potential tourist market for this oil was the basis for its selection here.
Melaleuca cajuputi Powell subsp. *cajuputi* (cajuput tree)	A small to medium-sized tree that occurs in northern Western Australia, 'Top End' of the NT and the Maluku islands region of Indonesia (Craven 1999; Doran 1999). The Cajuput tree occurs most commonly on low coastal plains subject to inundation.	A *trans*-nerolidol-rich (about 90% of total oil in the presence of linalool at about 5%) chemotype found in northern Australia was the focus here. *Trans*-nerolidol has an established market in perfumery where it is used as a base note in many delicate flowery odour complexes (Bauer *et al*. 1997).	*Trans*-nerolidol is presently sourced from cabreuva oil (about 80% *trans*-nerolidol of total oil), which is produced in South America from the wood of *Myrocarpus* spp. (Fabaceae) (Guenther 1952). Harvesting of this resource is said to be unsustainable (E. Lassak, pers comm.) providing a market opportunity for the *trans*-nerolidol-rich forms of other species.
Melaleuca ericifolia Smith (swamp paperbark)	A large shrub or small tree, often multi-stemmed, with a natural range from the central coast of NSW to Tasmania. It prefers low-lying, seasonally inundated areas within 50 km of the coast (Wrigley and Fagg 1993).	Brophy and Doran (2004) found oil rich in *d*-linalool (up to 60% of total oil at a concentration up to 4.5% w/w dry weight) in populations to the north of the species range in NSW. Linalool, with its fruity notes, is of value to the flavour and fragrance industries and, although it can be produced synthetically, there remains a market where natural linalool is preferred i.e. in aromatherapy (Coppen 1995).	Coppen (1995) reports that presently Chinese Ho oil (80–85% linalool of total oils) from *Cinnamomum camphora* is the major source of natural linalool in its *l*-enantiomer form. There might be market potential for the *d*-enantiomer of linalool, although the extent of this market is not known (Lassak 2005).
Melaleuca quinquenervia (Cav.) S.T. Blake (paperbark)	A small to medium-sized tree of the east coast of Australia, southern New Guinea and New Caledonia (Boland *et al*. 1984; Doran and Turnbull 1997, 1999; Trilles *et al*. 1999), where it occupies a wide range of soil types	The *trans*-nerolidol-rich (74–95%) and viridiflorol-rich (13–66%) chemotypes (Ireland *et al*. 2002) appeared to have the most potential and were selected for inclusion in this set of trials.	Foliar oil concentrations of both chemotypes south of latitude 25°S in Australia were a respectable 1–3% w/w fresh weight, but uniformly low (0.1–0.2%) to the north (Ireland *et al*. 2002). Unlike *trans*-nerolidol (see above), viridiflorol is little known (Webb 2000) and has no market history. It was a highly speculative inclusion in these trials.
Melaleuca viridiflora Sol. Ex Gaertner (broad-leaved paperbark)	A small tree most often found on infertile sites subject to seasonal inundation. It is very common throughout much of northern Australia. It also occurs in southern New Guinea (Boland *et al*. 1984; Doran and Turnbull 1997).	The methyl cinnamate-rich chemotype found on the Cape York Peninsula, Qld (latitude 15–16°S) was the focus here (Hellyer and Lassak 1968; Brophy and Doran 1996). Methyl cinnamate is a colourless, crystalline solid with a fruity, sweet-balsamic odour and its uses include as a flavour enhancer and in perfumery (Bauer *et al*. 1997). It can be produced artificially at relatively low cost.	A small market for natural methyl cinnamate from *E. olida* from northern NSW (Curtis *et al*. 1990) has existed for several years. Recently, however, demand has faded with supply coming from other sources outside of Australia (E. Lassak pers. comm.). The uncertain market makes this species a low priority in the context of this project.

(Nov. 2003). Simultaneously, the multiple long rows of four species were harvested for determination of broadacre oil yields. Provenances of *M. ericifolia* survived poorly and were excluded from both measurement and biomass determination. However, bulk samples of leaves were collected from each *M. ericifolia* treatment (10 trees sampled per treatment) before both harvests for determination of oil characteristics.

Determination of individual tree leaf biomass was undertaken on four replicates only (replicates 1–4 at first harvest and replicates 2, 3, 5 and 6 at second harvest) in the Dimbulah trial of tree species. The replicates assessed were chosen on their approximation to the mean height growth over the entire trial. All surviving trees in the selected replicates were cut near ground level, leaves and twigs (<2 mm diameter) were stripped and weighed, a subsample was taken and separated into pure leaf and twig. This ratio was then used to calculate total leaf biomass per tree. A 115-g sample of pure leaf was bagged, labelled and air-dried for later extraction to determine oil concentration and composition. The only exception was MV-mc, which had grown slowly and was not considered large enough to sample for estimation of leaf biomass and oil concentration at first harvest.

For practical reasons, the trials at Innot Hot Springs were measured less intensively than those at Dimbulah. They were assessed for height and survival and leaves were collected for oil analysis (two trees per plot from four replicates) at 14 months after planting (Nov. 2002) (growth data not given here). Estimation of broadacre oil yields at first harvest at this site took place 20 months (May 2003) from planting and estimation of yields at second harvest was undertaken 12 months (May 2004) later.

Determination of oil concentration by steam distillation in the laboratory in Canberra followed the methods of Brophy *et al*. (1991). Distillation time was 5 h throughout. The Essential Oil Unit of Wollongbar Agricultural Institute in NSW, determined the main components in the steam distilled oils using gas chromatography, following the methods described in Southwell *et al*. (2003). Analysing the variation in chemical composition between trees was restricted to eight trees per treatment [one randomly chosen oil (tree) × four replicates × two sites] due to cost constraints.

The long single-species rows adjacent to the trials at both sites were sampled to gain a more realistic estimation of oil yield (kg) per hectare on an operation scale. First harvest at Dimbulah took place immediately following measurement at 15.5 months after planting. At Innot Hot Springs, the first harvest was unavoidably delayed until 20 months after planting. Treatments MQ-tn, MQ-v, MC-tn and ES-ls were sampled at both sites at both harvests whereas treatments AS-c, ME1-dl, ME2-dl and ME3-dl were sampled only at Innot Hot Springs because of the poor growth or survival of these treatments at Dimbulah. Sufficient trees (25– 124 trees depending on species) of each treatment to fill the Department of Primary Industry's pilot commercial still (about 120 kg capacity) were harvested using a chain saw and secateurs. The plants were then finely chopped using a mulcher/chipper with a 2.5-cm screen. The mulched material was collected onto a plastic ground sheet and transferred to the distillation pot where the material was tightly packed by hand using a ram. Distillation times reflected those that might be applied in commercial operations with each species (i.e. 5 h for treatments MQ-tn, MQ-v, MC-tn and 2 h for treatments AS-c, ES-ls, ME1-dl, ME2-dl and ME3-dl). The results were summarised as actual oil yield (kg of oil/ha) based on stocking percentages at each site at each harvest.

Results

Analyses of variance (not given here) showed significant ($P < 0.05$) to highly significant differences ($P < 0.001$) between seedlots in all variates determined in the trials, as might be expected in a comparison of such diverse species and chemotypes.

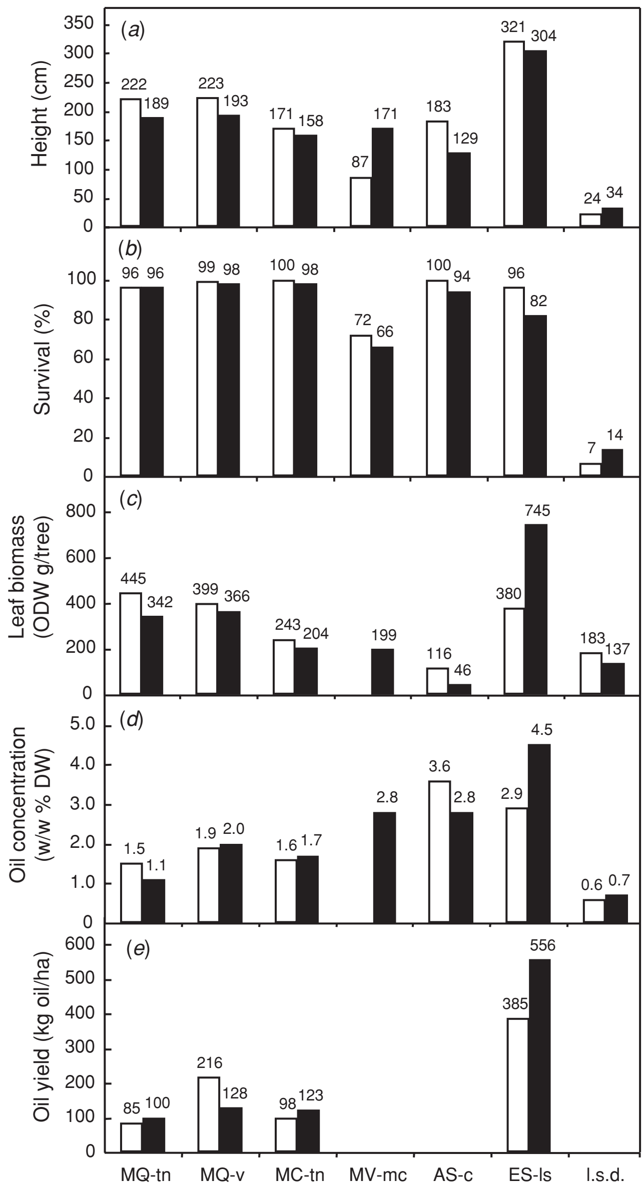

Fig. 1. The (*a*) height, (*b*) survival, (*c*) leaf biomass per tree, (*d*) oil concentration data from the trial of tree species, and (*e*) estimated broadacre oil yields from line plantings (white bars, first harvest, 15.5 months from planting; black bars, second harvest, 27.5 months from planting) using a pilot commercial still at Dimbulah. Codes for species–chemotype combinations are given in Table 1.

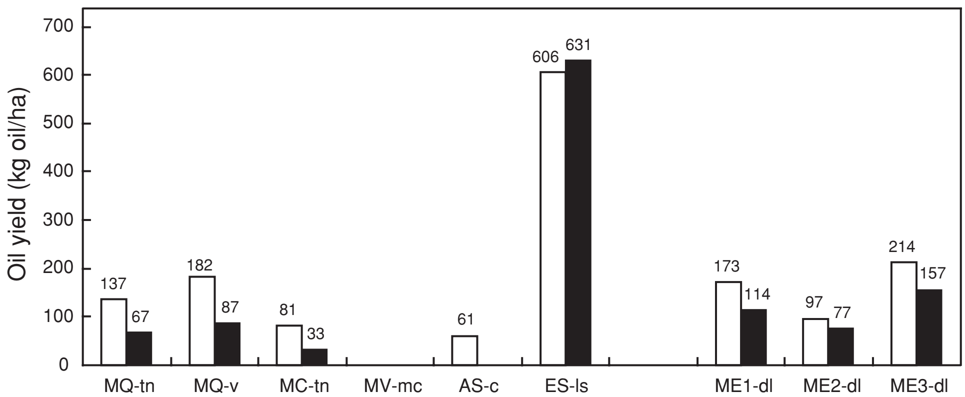

Fig. 2. Estimated broadacre yields from line plantings (white bars, first harvest, 20 months from planting; black bars, second harvest, 32 months from planting) using a pilot commercial still at Innot Hot Springs. Codes for species–chemotype combinations are given in Table 1.

Growth, survival, leaf biomass, essential oil concentration and yield data (where assessed) for all tree species at Dimbulah over two harvests are summarised in Fig. 1. Fig. 2 gives oil yield data (where assessed) for all treatments including *M. ericifolia* at Innot Hot Springs. Growth and essential oil concentration data for the tree species before first harvest at Innot Hot Springs closely followed the trends at Dimbulah (data not presented).

For two, *M. quinquenervia* (MQ-tn and MQ-v) and *M. cajuputi* subsp. *cajuputi* (MC-tn), of the three broad-leaved melaleucas in these trials, survival was excellent for all three seedlots under test. Growth and oil yields of all three seedlots at first harvest were good, with oil yields for MQ-v excellent at near 200 kg/ha. The substantial reduction in yield at second harvest for treatments MQ-tn and MC-tn at Innot Hot Springs and treatment MQ-v at both sites was disappointing and a direct result of damage to growing tips by Coreid bug attack.

The results for MV-mc and AS-c were unimpressive. *M. viridiflora* averaged 0.7 m height growth per year over the two sites and survival averaged less than 60%, 30 months after planting. No yield estimates for this species were undertaken because of the slow growth. *A. symphyocarpa* grew quite well to first harvest where it averaged 1.7 m in height growth in ~15 months from planting over the two sites. However, leaf biomass production was poor and the first harvest yield was not assessed at Dimbulah and, at Innot Hot Springs, was only 61 kg of oil/ha. Survival of *A. symphyocarpa* after coppicing was good (95%) but coppice growth was slow (height growth <1 m in 12.5 months). Oil yields for this species were not determined at either site at second harvest because of slow growth.

ES-ls was the best performing species in terms of growth rate and oil yields at both sites with oil yields averaging 470 kg of oil/ha at Dimbulah (Fig. 1) and a very impressive 618 kg of oil/ha at Innot Hot Springs, averaged over the two harvests (Fig. 2). Survival at second harvest had slipped to 82% at Dimbulah but had not declined between harvests at Innot Hot Springs.

Table 3. Ranges in oil concentration of the species by chemotype obtained under trial at Dimbulah and Innot Hot Springs in northern Queensland

Percentages of total oil of the major compounds were assessed over two harvests at both sites unless otherwise indicated

Species–chemotype code	Species	Range in oil concentrations (w/w % DW)	Principal oil constituent	Principal oil constituent as a percentage of total oil (%)
		Tree form trial at wider spacing		
MQ-tn	*M. quinquenervia*	0.6–2.8	*Trans*-nerolidol[A]	85–96
MQ-v	*M. quinquenervia*	1.2–3.3	Viridiflorol	21–50
ME-tn	*M. cajuputi*	0.3–2.7	*Trans*-nerolidol[A]	66–83
MV-mc	*M. viridiflora*	1.4–3.2[B]	Methyl cinnamate	82–94
AS-c	*A. symphyocarpa*	1.1–4.7	1,8-cineole	48–57
ES-ls	*E. staigeriana*	0.9–6.8	Citral	21–38
		M. ericifolia trial at close spacing		
ME1-dl	*M. ericifolia*	1.1–3.1	*d*-Linalool	36–47
ME2-dl	*M. ericifolia*	1.2–1.9	*d*-Linalool	26–46
ME3-dl	*M. ericifolia*	1.2–2.3	*d*-Linalool	38–45

[A]Two out of eight trees were a different chemotype and were excluded from this summary.
[B]Dimbulah at second harvest only.

M. ericifolia (ME1-dl, ME2-dl and ME3-dl) failed at Dimbulah where survival had declined to 43% by time of first harvest 15.5 months after planting and very few trees remained by time of second harvest. Performance was much better at Innot Hot Springs, although survival had slipped to 65% and 62% for two of the provenances by the time of second harvest, substantially reducing the oil yields obtained from the pilot commercial still (Fig. 2). If the survival problems with this species could be overcome, then yields greater than 200 kg/ha per harvest should be achievable.

Although data on variation in oil concentration, main oil constituents and their percentage of total oil, varied depending on species, provenance and individual tree, there did not appear to be any major differences associated with harvest time or site. Accordingly, all available data from the two harvests and two sites were combined and a summary is provided in Table 3. Two out of the eight trees chemically assayed in treatments MQ-tn and MC-tn were of a different chemotype to that targeted. In the case of MQ-tn, two trees were viridiflorol-rich and for MC-tn, two trees were rich in an unidentified sesquiterpene alcohol. *E. staigeriana* gave one non-lemon scented individual that was rich in 1,8-cineole. The maximums for *d*-linalool percentage in the oils of the three *M. ericifolia* populations were less than might have been anticipated as these seedlots were based on mature trees in nature with oils of 50–60% *d*-linalool.

Discussion

Large ranges in individual tree oil concentrations recorded in nearly all treatments are typical of similar data from many essential oil source species (e.g. Southwell and Lowe 1999; Coppen 2002). Oil concentration has been found to be highly heritable in all the *Melaleuca* and *Eucalyptus* species studied to date, allowing plenty of scope for rapid advancement through genetic improvement programs (Doran 2002; Doran *et al*. 2002). There is no reason to expect that yields of these species could not be improved greatly through selection and breeding. The occurrence of different chemotypes in the progeny of these open pollinated seedlots from natural stands where different chemotypes co-occur is also to be anticipated (Brophy and Lassak 1988). Oil composition has also been found to be highly heritable in various *Melaleuca* and *Eucalyptus* species (Doran 2002; Doran *et al*. 2002), and would also be open to improvement through selection and breeding. The upper levels of *d*-linalool in the *M. ericifolia* oils (about 46%) were surprisingly low given the selection of seed trees at each provenance with oils containing 50–60% *d*-linalool. A similar result has been reported by growers in northern NSW and it appears that development of a stable oil composition in *M. ericifolia* may be a longer process than in the other species. Clonal forestry is an option with many melaleucas and tropical eucalypts and could be employed to great advantage in these species to increase yields and oil qualities (Doran *et al*. 2000).

The exceptionally good yields (400–600 kg per harvest) from *E. staigeriana* in these trials far exceeded the annual yields reported in Brazil (100 kg/ha), the main source of this oil type (Couto 2002). Bulk *E. staigeriana* oil from Brazil, however, is both cheap and in plentiful supply (E. Lassak, pers comm.) effectively limiting production in northern Qld to the small quantities needed to service local demand for the oil as an insect repellent and the tourist market.

Trans-nerolidol, linalool and methyl cinnamate are accepted articles of commerce and have already been subject to the expensive regulatory procedures and safety testing that limit development of new oils (Lassak 2005). These can be fractionated from crude essential oils of the correct type and openly traded on the global market. Use of *M. ericifolia* as a source species for *d*-linalool production in the tropics, would carry too great a risk of failure from the results of these trials, and more work would be needed to underpin any such plans. *A. symphyocarpa* and the methyl cinnamate form of *M. viridiflora* were simply too slow growing to warrant further consideration of their plantation potential. *M. cajuputi* subsp. *cajuputi* gave a similar performance to *M. quinquenervia*. The rarity of the *trans*-nerolidol form of this species and remoteness of its natural occurrence are impediments to further planting and research.

Of the source species of these compounds tested in this set of trials, the *trans*-nerolidol form of *M. quinquenervia* appears to have the greatest potential for further development. First harvest yields of the one *trans*-nerolidol-rich *M. quinquenervia* seedlot included in these trials were reasonable (averaging 111 kg/ha) but declined dramatically at second harvest at Innot Hot Springs (67 kg/ha). Even the increase in yield at second harvest at Dimbulah to 100 kg/ha was much less than might have been expected based on experience with *M. alternifolia*, where second harvest yields are some 25–50% greater than yields at initial harvest (Colton *et al*. 2000). As Coreid bug was only partially controlled at Dimbulah with two applications of insecticide and not at all at Innot Hot Springs, we can confidently predict that second harvest yields could have been much improved with better insect control. There is also significant scope for improvement through testing and selection of better-adapted seed sources for growth in the tropics and tree breeding. It is not unreasonable to expect that yields of this chemical form could quickly approach the excellent first harvest yields of the viridiflorol-rich *M. quinquenervia*, which averaged 200 kg/ha over the two sites. Market and benefit–cost analyses and further provenance and silvicultural research, would appear to be the logical next steps in assessing the potential of this oil type as a parallel cropping option or alternative to production of *M. alternifolia* oil in northern Qld.

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