Indian Sandalwood

Harvest of Indian sandalwood (*Santalum album L.*) and determination of heartwood yield, sandalwood oil yield and sandalwood oil quality from plantations at Kununurra, Western Australia

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The aromatic heartwood from Indian sandalwood (*Santalum album)* is a much sought after commodity with high prices being demanded for it along with high prices for the volatile oil extracted from the heartwood.

From the early 1980s Australia's Forest Department (later absorbed into the Department of Conservation and Land Management) trialled Indian sandalwood on the Ord River Irrigation Area (ORIA) at Kununurra, Western Australia. These trials indicated that the area was suitable for the development of commercial plantations.

Over the next 25 years research plots and extensive commercial plantations have been established in the ORIA. Today there is in excess of 5,000 ha under plantation the majority held by two private companies, namely Tropical Forestry Services (TFS) and Elders Forestry.

There has been some experimental work undertaken to estimate heartwood and sandalwood oil yields in these plantations, but these have been undertaken by sampling bark to bark cores or disks from felled trees.[1,2]

This investigation used whole sandalwood trees that were harvested from research plots now managed by the Forest Products Commission Western Australia (FPC). Heartwood yield, volatile oil yield and volatile oil quality were investigated. These trees represented some of the first plantings of Indian sandalwood in the ORIA.

FPC, TFS and Mt. Romance Australia Pty. Ltd. (MRA) cooperated in harvesting and processing the material. FPC is the government body responsible for the initial trials and establishment of Indian sandalwood in the ORIA. TFS is a leading organization in Indian sandalwood plantation management in the world and MRA is one of the largest processors of sandalwood into sandalwood oil.

Methods

Ninety trees were selected for harvest from four trial plots managed by the FPC. Selection of trees was made from those available to provide a representative cross-section of trees in each compartment. The selection was carried out with the assistance of the FPC. The source of trees is shown in **T-1**.

Harvest: Harvest of the 90 trees was conducted by the FPC. At harvest, trees were cut at ground level and cut into lengths of up to 1.2 m; each piece was individually marked with a number to identify the tree. The underground butt and root mass was extracted using a mini excavator and the tree identity number applied to the butt.

Root material containing heartwood was collected with a record of its harvest block origin. Root material not containing heartwood was trimmed and left in the field.

The tree was then trimmed to remove leaves and branches with a diameter less than 25 mm. Trimmed material was left in the field.

Sorting: Trees were delivered to the TFS premises in Kununurra, where the material was sorted into its various components:

- Unclean logs (logs containing heartwood with a diameter greater than 20 mm at either end)
- "B" logs (logs and branches containing no aromatic heartwood or heartwood less than 20 mm at the big end and with a small end diameter [SED] of greater than 30 mm)
- Butts (the underground extension of the bole trimmed of all radiating roots)
- Roots (containing heartwood with a diameter equal to or greater than 20 mm at either end)

Debarking: Most of the material was debarked in a drum, with the remainder being debarked using a 4,000 psi pressure washer.

Determination of heartwood: Determination of heartwood contained in logs and some butts was made by application of Smalian's formula: $(A1 + A2)/2 \times L$ where A1 = area of end 1, A2 = area of end 2, and L = length.

Some butts were sectioned and the volume of heartwood calculated from these sections by physical counting

At a Glance

The harvest of 90 Indian sandalwood trees represents the first commercial-size harvest of mature sandalwood from the Ord River Irrigation Area (OIRA). The investigation found that Indian sandalwood grown under plantation conditions in the ORIA produced commercial yields of heartwood and sandalwood oil that is of a quality suitable for commerce.

A strong correlation was observed between diameter over bark at 20 cm, merchantable mass, heartwood and sandalwood oil yield. This is contributing to the development of a predictive model for these characteristics in standing trees, which is the subject of ongoing research.

of squares. Areas were calculated using *Image J* software, calibrated to images of each cross-section and length was measured using a standard tape measure. The average density of wood was also calculated by dividing weight by volume on a sample of logs. This figure was used to convert volume into weight for heartwood estimate.

Heartwood determination was made on roots by sorting a sample of chipped roots into heartwood and non-heartwood and proportions determined by weight. Weights were then distributed to individual trees based on butt mass.

Laboratory estimation of sandalwood oil yield: Laboratory estimation of oil yields was conducted on all trees with the exception of four trees in total, these being one tree from harvest block 8C2, two trees from harvest block 8C5 and one tree from harvest block RD. These trees were retained whole. Heartwood was separated from sapwood by bandsaw and block hydraulic splitter.

Indian sandalwood roots, cleaned sandalwood logs and butts were chipped and pre-ground to a size that MRA finds optimal for its sandalwood distillation. All trees were chipped and ground to fit through an eight-mesh sieve on an individual tree basis with samples from each tree taken. Roots which were collected on a harvest block level were chipped and ground separately with laboratory estimates conducted on this material and estimates distributed amongst trees based on butt mass.

Laboratory estimate of oil yield and quality was made by using hydrodistillation of a 20 g sample for 15 h using a modified Dean-Stark trap. Volatile oil was collected from the trap and the trap rinsed three times with n-hexane. The washings were added to the contents of the trap in a separation funnel and the oil phase collected. The washings were then combined and the hexane removed by rotavap at 60°C under vacuum in a tared flask. The flask was then weighed and the yield calculated by subtracting the tare. The recovered oil was then collected and retained.

Constituents in the recovered oil were identified using GC-FID under the following conditions: Shimadzu GC17A with an AOC–20 autosampler; column: Rtx-1, 30 m x 0.25 m x 0.25 mm, 1 m pre-column; carrier gas: hydrogen at 35 cm/sec; detector: FID, 300°C; temperature

Summary of trees selected for harvest **T-1**

Harvest block	Block name	No. trees harvested	Year planted	Age
2A	2A	36	1988	22
8C2	8C EKD2	10	1990	20
8C5	8C EKD5	20	1991	19
RD	Richmond	24	1987	23

Total merchantable wood yield from each harvest block; weights were debarked and recorded when wood was measured at MRA **T-2**

Harvest block	Total merchantable wood (kg)	Mean merchantable wood per tree (kg)	Lowest tree weight (kg)	Highest tree weight (kg)	Number of trees in sample
2A	4,091	114	32	510	36
8C2	3,190	319	208	555	10
8C5	1,969	98	49	240	20
RD	2,524	105	23	356	24
Total	**11,774**	**131**			**90**

Heartwood yield from each harvest block; calculated from volumetric measurements, using a specific gravity of 0.95 at a moisture content of 25% **T-3**

Harvest block	Total aromatic heartwood (kg)	Mean aromatic heartwood per tree (kg)	Lowest yield (kg)	Highest yield (kg)	Number of trees in sample
2A	713	19.8	5	69	36
8C2	705	70.5	45	118	10
8C5	410	20.5	9	40	20
RD	479	20.0	3	87	24
Total	**2,307**	**25.6**			**90**

program: 50°C (1 min), 30°C/min to 100°C, 5°C/min to 190°C, 20°C/min to 250°C (10 min).

The laboratory yield was then used to calculate a per tree yield based on the amount of heartwood determined by previous measurement.

Production yields: Production equipment at MRA was used to steam distill Indian sandalwood. Two to three individual trees from each harvest block were steam distilled individually to verify laboratory yields. Steam distillation was undertaken using standard operating procedures.

The gross oil yield was calculated on the dried oil weight. Water was removed from the recovered oil by heating to 80°C under vacuum.

Results

Merchantable wood: Merchantable wood is defined as the total amount of wood which has commercial value and includes heartwood and sapwood. It was calculated on a per tree basis; **T-2** and **F-1** summarize these findings.

Heartwood: Heartwood was identified and its weight determined on a per-tree basis. **T-3** and **F-2** summarize these results.

Sandalwood oil yield: Sandalwood oil yield from heartwood was determined by laboratory scale hydrodistillations of heartwood from individually chipped trees. **T-4** and **F-3** detail these results. Note that four trees were retained whole and not subject to chipping and volatile oil determination. These comprised one from 8C2, two from 8C5 and one from RD.

Sandalwood oil quality: The quality of the oil obtained by laboratory distillation was assessed by α-santalol and ß-santalol concentration in the oil obtained from the laboratory scale hydrodistillation of the chips sourced from each whole tree. This was undertaken using GC-FID; **T-5** details the results.

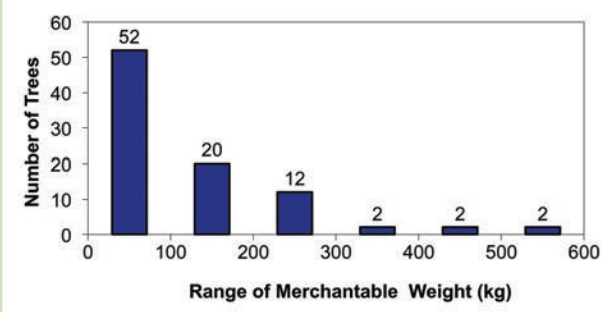
Results of commercial-size distillations: The chipped sandalwood heartwood was subject to steam distillation through MRA's commercial steam distillation plant. A total of 24 distillations were undertaken. For fine fragrance use, the recovered oil will need to be subject to rectification in order to remove some of the terpenes (**T-6**).

The 24 distillations were blended together and the quality of the resulting oil was assessed against the ISO standard; the results are detailed in **T-7**.[3]

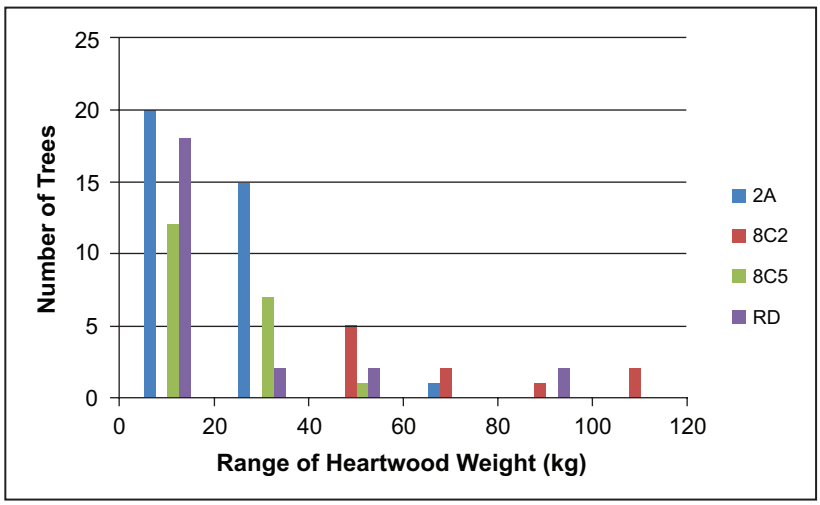
Discussion

Stocking rates: Limited information on stocking rates was available and these are shown in **T-8**. The reasons for

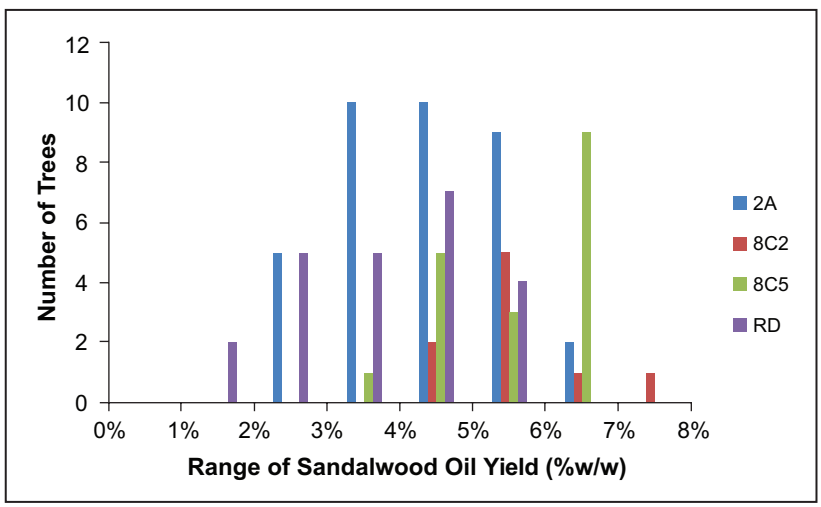
Distribution of merchantable weight of wood from the 90 trees harvested **F-1**



Range of aromatic heartwood yields from all harvest blocks F-2



Range of sandalwood oil yield from heartwood from all harvest blocks F-3



Laboratory scale Indian sandalwood oil yield from heartwood T-4

Harvest block	Mean oil yield from heartwood (% w/w)	Lowest yield (% w/w)	Highest yield (% w/w)	No. trees analyzed
2A	4.4%	2.4%	6.5%	36
8C2	5.6%	4.9%	7.3%	9
8C5	5.6%	3.9%	6.9%	18
RD	4.2%	1.7%	5.5%	23
Mean	**4.9%**			

attrition are unclear due to a lack of records, but could be a combination of deaths and prior selective harvests.

Moisture: Varying amounts of moisture were found within the harvested sandalwood, with the following levels identified:

- After drum debarking in Kununurra, 40%
- On receipt at MRA Albany, 25%
- After chipping at MRA Albany, 13%

This report has used a moisture level on receipt at MRA (25%) for presentation of results.

Definition of heartwood: The investigation found three distinct types of wood within each cross-section of the tree. The first outer layer or sapwood was a pale yellow color, contained no sandalwood odor and did not contain significant quantities of sandalwood oil. The sapwood represented approximately the first centimeter of each cross-section, although this did vary and there was a poorly defined boundary between it and the next layer, transitional heartwood.

Transitional heartwood was a very light pink/red color and had more pronounced growth rings than the sapwood layer. This wood contained no sandalwood odor and did not contain significant quantities of sandalwood oil. This layer varied in percentage of diameter from tree to tree and there was a well-defined boundary between this layer and the underlying aromatic heartwood.

Aromatic heartwood, which this paper refers to as "heartwood," is brown to yellow in color and has a strong sandalwood odor and occupies the center part of the cross section. This part of the tree has commercially extractable quantities of sandalwood oil. It was noticed that as wood was examined further up a tree the percentage of aromatic heartwood decreased and the percentage of transitional heartwood increased.

This paper only refers to the aromatic heartwood in its discussion on heartwood because it contains commercial quantities of

Concentrations of α-santalol and β-santalol in oil recovered from laboratory scale hydrodistillations of individual trees **T-5**

Harvest block	Mean α-santalol (% w/w)	Mean β-santalol (% w/w)	Highest α-santalol	Lowest α-santalol	Highest β-santalol	Lowest β-santalol
2A	47.7	21.4	50.9	45.8	24.9	19.0
8C2	47.5	20.7	49.9	44.3	22.1	19.3
8C5	46.4	21.1	49.3	42.4	24.1	17.8
RD	48.0	21.7	50.5	44.0	23.3	19.1
Mean	**47.4**	**21.2**				

Comparison of yield estimates from laboratory distillations against actual yields achieved when distilled in production equipment **T-6**

Weight of heartwood distilled (kg)	Production estimate (kg)	Actual production (kg)
1994	96.1	91.3
Yield (%w/w)	4.8%	4.6%

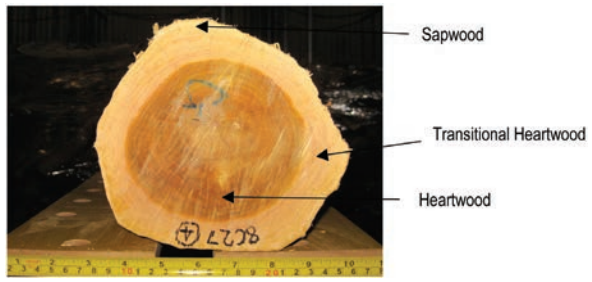
sandalwood oil and represents the part of the tree which demands the high prices afforded to sandalwood.

F-4 demonstrates the types of wood found in a cross-section of Indian sandalwood.

Heartwood: All of the heartwood recovered was suitable for oil extraction and all but four trees were subject to distillation through MRA's plant. Four trees were retained as samples, three of which had solid pieces of heartwood; their acceptance as carving logs has been assessed as suitable.

Commercial quantities of heartwood were obtained from all harvest blocks and all the heartwood was suitable for sandalwood oil extraction, whilst some heartwood was deemed suitable for carving and other traditional heartwood uses.

Typical cross-section of Indian sandalwood showing the three types of wood; note the poor boundary between the sapwood and transitional heartwood **F-4**



The harvest block 8C2 was an outstanding performing block with large trees containing large amounts of heartwood that was solid and mostly suitable for carving. Harvest block 8C5 also produced good solid pieces of heartwood.

Sandalwood oil yield from heartwood: The investigation indicated that commercial yields of sandalwood oil are available from heartwood. Laboratory estimates of mean sandalwood oil yield from heartwood were 4.9% w/w whilst in production yields of 4.6% w/w from heartwood were achieved.

Quality results from commercial distillation of sandalwood oil from trial harvest **T-7**

Test	Harvest result	ISO specification
Appearance	Clear, slightly viscous liquid	Clear, slightly viscous liquid
Color	Light yellow	Almost colorless to golden yellow
Odor	Characteristic, sweet, woody and persistent	Characteristic, sweet, woody and persistent
Specific gravity @ 20°C	0.969	0.968-0.983
Refractive Index @ 20°C	1.504	1.503-1.509
Solubility in 70%v/v ethanol @ 20°C	1.8	<5
Optical rotation @ 20°C	-17°C	-21°C to -17°C
Z-α-santalol	47.1%	41–55%
trans-α-bergamotol	5.8%	
epi-β-santalol	3.7%	
Z-β-santalol	19.3%	16–24%

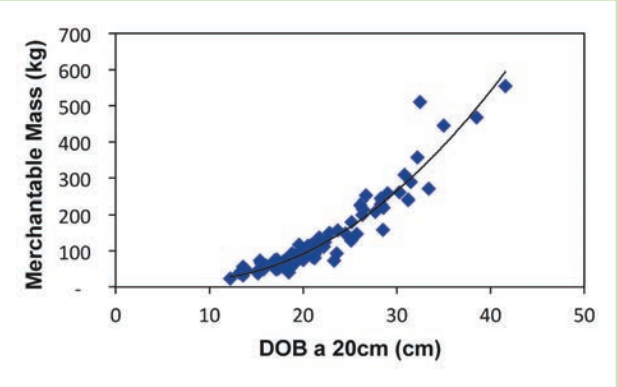
Stocking rates for trees from trial harvest **T-8**

Harvest block	Initial stocking rate (stems ha^{-1})	Initial spacing	Stocking at harvest (stems ha^{-1})
2A	Unknown	Unknown	93
8C2	460	7.2 m x 3.0 m	218
8C5	460	7.2 m x 3.0 m	185
RD	Unknown	Unknown	85

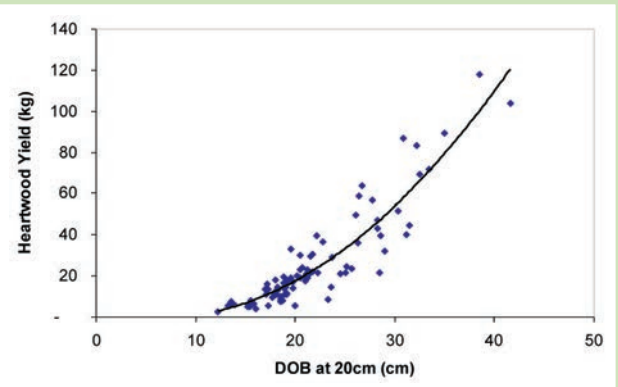
Comparison of mean sandalwood oil yield per tree for each harvest block **T-9**

Harvest block	Laboratory mean oil Yield per tree (kg)	Production mean oil Yield per tree (kg)
2A	0.87	n/d
8C2	3.92	n/d
8C5	1.18	n/d
RD	0.72	n/d
Total	**1.22**	**1.15**

Relationship between DOB at 20 cm and merchantable mass for all harvest blocks; y = 0.52x^2 - 8.29x + 51.58, R^2 = 0.9225, n = 90 **F-5**



Relationship between diameter over bark (DOB) at 20 cm and aromatic heartwood yield; R2 = 0.84, n = 90, y = 0.098x^2-1.26x + 3 **F-6**



The best sandalwood oil yields were obtained from harvest block 8C2 and 8C5. This was due to most wood from these trees being solid and some trees from blocks 2A and RD being affected by damage due to infection or insects.

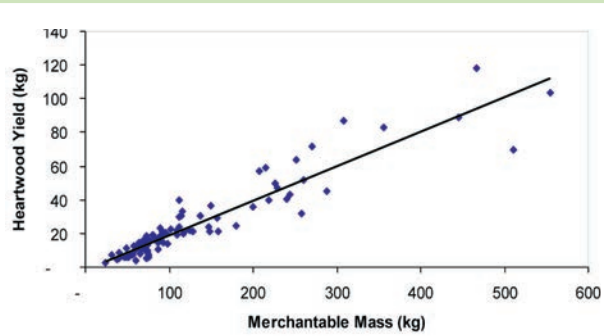
By combining average heartwood yield per tree and average sandalwood oil yield from heartwood it is possible to see mean sandalwood oil yield per tree (**T-9**).

Sandalwood oil quality: Analysis of sandalwood oil obtained from laboratory distillation of individual trees found that the constituents varied little between trees and that all trees produced oil that complied with the constituent specification contained in the ISO specification.

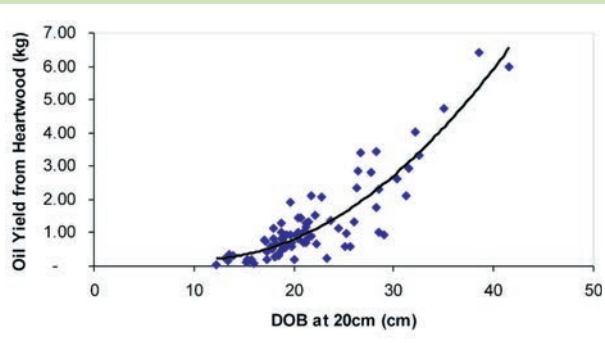
The sandalwood oil recovered from commercial steam distillation of the heartwood complied with the ISO standard for Indian sandalwood oil.[3]

Relationship between diameter over bark (DOB), merchantable mass, heartwood yield and sandalwood oil yield from heartwood: A number of significant relationships were observed between measured parameters in the trial harvest. These are highly relevant as they indicate that models can be developed to measure merchantable mass and heartwood yield in standing trees.

Relationship between total merchantable mass and aromatic heartwood yield; R2 = 0.88, n = 90, y = 0.205x-1.13 **F-7**



Relationship between diameter over bark at 20 cm and sandalwood oil yield (kg); R2 = 0.84, n = 86, y = 0.0065x^2 - 0.13x + 0.87 **F-8**



It was also very apparent that there is a strong relationship between the size of a tree and its yield of heartwood and sandalwood oil (**F-5**, **F-6**, **F-7** and **F-8**).

Conclusion

This investigation found that sandalwood grown under plantation conditions in the ORIA produced commercial yields of heartwood and sandalwood oil that are of a quality suitable for commerce. Thus the findings of this report support the establishment and continued development of a plantation-grown Indian sandalwood industry in the ORIA.

The commercial yields observed were from some of the first plantings of sandalwood in the ORIA. The industry's understanding of silvicultural practices required to successfully grow Indian sandalwood has developed significantly since these trees were established. This further supports the view of this report that plantation grown Indian sandalwood has a bright future in the ORIA.

The investigation found a number of good correlations between diameter over bark at 20 cm, merchantable mass yield and heartwood yield. These relationships along with the observed oil yield from heartwood are important in the development of a predictive model. This model is the subject of current research at TFS.

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2. C Jones, J Plummer and L Barbour, Non-Destructive Sampling of Indian Sandalwood (*Santalum album*) for Oil Content and Composition. *J Essent Oil Res*, **19**, 157–164 (2007).
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