PRESCRIBED BURNING
IN QUEENSLAND
EXOTIC PINE PLANTATIONS

FORESTRY

P. J. BYRNE

DEPARTMENT OF FORESTRY, QUEENSLAND

PREPARED FOR THE ELEVENTH COMMONWEALTH FORESTRY CONFERENCE

TRINIDAD

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APPENDIX 2.

F.D.O.490B

PRESCRIBED BURNING GUIDE

(Slash Pine Plantation)

(Mk. III)

FUEL TYPES

The fire behaviour tables used in this guide apply to Slash Pine plantation fuels which have not been burnt previously, and which may exceed 18 tonnes per hectare in weight.

Fuel Type 1. Fuel Suspension on 50% of area.
Fuel Type 2. Fuel Suspension on 50-80% of area.
Fuel Type 3. Fuel Suspension on 80% of area. Fuel is suspended in dense understorey of Xanthorrhoea, Bracken.
Fuel Type 4. Dense understorey of Blady Grass.
Fuel Type 5. Ladder fuels. Fuel is suspended in dense understorey of tea-tree etc.

Fuel types should be mapped on the above basis prior to the development of the burn prescription.

The Fire Behaviour Tables refer to an average fuel condition. Fires in Type 1 will be milder than indicated in the tables; Fires in types 3, 4 & 5 will be hotter.

DRYING TABLES

Select an appropriate drying table on page 2 on the basis of average maximum temperature of the drying period. Actual temperature should be used for unseasonal conditions, otherwise the mean monthly temperature indicated at the foot of page 2 may be adopted.

WARNING: ***Burning must not be attempted unless a minimum of 7 mm of rain has been registered on the burn area.***

BURN PRESCRIPTION

Any burn prescription must be based on the following maximum recommended flame heights.

Site Index (m)	AGE (years)					
	10	12	14	16	18	20
18	0.5 m	0.7 m	0.8 m	0.9 m	1.1 m	1.2 m
21	0.6 m	0.8 m	1.0 m	1.1 m	1.2 m	1.4 m
24	0.8 m	1.0 m	1.1 m	1.2 m	1.4 m	1.5 m

LIGHTING TECHNIQUES

(1) **Strip Backfire.** Light on a face or at 20-30 metre intervals along the downwind edge of the block. This is the safest method of burning heavy fuels (types 3, 4) or in poor site index or young stands, or in very exposed sections of a block. Spread rate will be about half, and flame height two-thirds of that indicated in the tables. Use this technique where headfires may be too active, particularly when wind is Force 3-4.

(2) **Strip Headfire.** Light on a face or at 20-30 metre intervals along the windward edge of the block. Use this method when wind speed is low and fuel moisture content too high for backfires to spread, such as burning plantation edges following rain.

(3) **Grid Ignition.** Calculate a grid spacing from the predicted Rate of Spread such that the individual fires will link up in about 2 hours. Spots must never be lit to within one grid spacing of the edge of the edge of the plantation on the downwind side, or half a grid spacing on the windward side.

Grid spacing may be varied to suit changing fuel type or weather conditions. Most areas will be grid lit after burning exposed sections by strip head or back fires.

FIRE BEHAVIOUR TABLES

(These figures refer to fires lit at a single point and allowed to spread; Fires lit on a face or in strips will be approx. 1.5 times as hot.
R = forward rate of spread in metres/h H = flame height in metres.
Figures in brackets apply to exposed areas.)

(1) First Suitable Burning Day After Rain.
(Available Fuel = 8 t/ha, Fuel Moisture Content 30–35%)

Relative Humidity	Wind Strength			
	Force 1 1 – 5 km/h	Force 2 6 – 11 km/h	Force 3 12 – 18 km/h	Force 4 19 – 29 km/h
15%	R = 32 (41) H = 0.8 (0.9)	R = 36 (46) H = 0.9 (1.0)	R = 43 (59) H = 1.0 (1.2)	R = 63 (92) H = 1.3 (1.7)
25%	R = 27 (34) H = 0.7 (0.8)	R = 31 (41) H = 0.8 (0.9)	R = 38 (52) H = 0.9 (1.1)	R = 54 (83) H = 1.1 (1.6)
35%	R = 22 (29) H = 0.7 (0.7)	R = 27 (36) H = 0.7 (0.9)	R = 34 (45) H = 0.8 (1.0)	R = 45 (74) H = 1.0 (1.4)
45%	R = 18 (23) H = 0.6 (0.6)	R = 23 (31) H = 0.6 (0.8)	R = 31 (40) H = 0.8 (0.9)	R = 40 (65) H = 0.9 (1.3)
55%	R = 14 (18) H = 0.5 (0.6)	R = 18 (25) H = 0.6 (0.7)	R = 25 (34) H = 0.7 (0.8)	R = 32 (56) H = 0.8 (1.2)
65%	R = 11 (14) H = 0.5 (0.5)	R = 14 (20) H = 0.5 (0.6)	R = 18 (29) H = 0.6 (0.7)	R = 25 (49) H = 0.7 (1.1)
75%	R = 7 (11) H = 0.4 (0.5)	R = 11 (14) H = 0.5 (0.5)	R = 14 (23) H = 0.5 (0.6)	R = 16 (41) H = 0.5 (0.9)
85%	R = 5 (7) H = 0.4 (0.4)	R = 7 (11) H = 0.4 (0.5)	R = 11 (18) H = 0.5 (0.6)	R = 11 (34) H = 0.5 (0.8)

(2) Second Suitable Burning Day After Rain
(Available Fuel = 12 t/ha, Fuel Moisture Content 25 – 30%)

Relative Humidity	Wind Strength			
	Force 1 1 – 5 km/h	Force 2 6 – 11 km/h	Force 3 12 – 18 km/h	Force 4 19 – 29 km/h
15%	R = 38 (49) H = 0.9 (1.1)	R = 43 (54) H = 1.0 (1.1)	R = 52 (70) H = 1.1 (1.4)	R = 76 (112) H = 1.5 (2.0)
25%	R = 32 (41) H = 0.8 (0.9)	R = 36 (47) H = 0.9 (1.0)	R = 45 (61) H = 1.0 (1.3)	R = 63 (101) H = 1.3 (1.9)
35%	R = 27 (34) H = 0.7 (0.8)	R = 32 (41) H = 0.8 (0.9)	R = 40 (54) H = 0.9 (1.1)	R = 54 (90) H = 1.1 (1.7)
45%	R = 23 (29) H = 0.6 (0.7)	R = 29 (36) H = 0.7 (0.9)	R = 36 (47) H = 0.9 (1.0)	R = 47 (81) H = 1.0 (1.6)
55%	R = 18 (23) H = 0.6 (0.6)	R = 22 (31) H = 0.6 (0.8)	R = 31 (41) H = 0.8 (0.9)	R = 40 (72) H = 0.9 (1.4)
65%	R = 14 (18) H = 0.5 (0.6)	R = 18 (25) H = 0.6 (0.7)	R = 25 (36) H = 0.7 (0.9)	R = 32 (65) H = 0.9 (1.3)
75%	R = 11 (14) H = 0.4 (0.5)	R = 14 (20) H = 0.5 (0.6)	R = 18 (31) H = 0.6 (0.8)	R = 25 (58) H = 0.7 (1.2)
85%	R = 7 (11) H = 0.4 (0.4)	R = 11 (14) H = 0.4 (0.5)	R = 14 (25) H = 0.5 (0.7)	R = 18 (50) H = 0.6 (1.1)

DRYING TABLES

(Figures indicate weight of fuel (tonnes per ha) available for burning)

Where the effect of one rain period is superimposed on that of another, all rain registered should be taken into account

30° C

No. Days Since Rain	Rainfall (mm)				
	2.5	7.5	12.5	25	40
1	18	12		TOO	WET
2		18	12	12	
3			18	18	12
4	TOO	DRY			18
5					

28° C

No. Days Since Rain	Rainfall (mm)				
	2.5	7.5	12.5	25	40
1	18	12		TOO	WET
2		18	12		
3			18	12	12
4	TOO	DRY		18	16
5					18

26° C

No. Days Since Rain	Rainfall (mm)				
	2.5	7.5	12.5	25	40
1	12			TOO	WET
2	18	12	12		
3		18	16	12	8
4			18	16	12
5	TOO	DRY		18	16
6					18
7					

24° C

No. Days Since Rain	Rainfall (mm)				
	2.5	7.5	12.5	25	40
1	12				
2	16	12		TOO	WET
3	18	16	12		
4		18	16	12	8
5			18	16	12
6	TOO	DRY		18	16
7					18

22° C

No. Days Since Rain	Rainfall (mm)				
	2.5	7.5	12.5	25	40
1	8				
2	12	8			
3	16	12	8		
4	18	16	12	8	
5		18	16	12	8
6			18	16	12
7				18	16
8					18
9					
10					

20° C

No. Days Since Rain	Rainfall (mm)				
	2.5	7.5	12.5	25	40
1					
2	8				
3	12	8			
4	16	12	8		
5	18	16	12	8	
6		18	14	12	8
7			16	14	12
8			18	16	14
9				18	16
10					18

5 tonnes per ha = 1 cm of dry surface needles
10 tonnes per ha = 2 cm of dry surface needles
15 tonnes per ha = 3 cm of dry surface needles
20 tonnes per ha = 4 cm of dry surface needles

MEAN DAILY MAXIMUM TEMPERATURE

Locality	March	April	May	June	July	August
South Queensland	28	26	23	21	20	22
Central Queensland	30	28	25	23	23	24
North Queensland	30	29	27	26	25	26

EXPOSED AREAS

Moisture conditions suitable for effective burning of exposed edges will occur one to two days earlier than indicated in the above drying tables.

(3) Third Suitable Burning Day After Rain
(Available Fuel = 16 t/ha, Fuel Moisture Content 20-25%)

Relative Humidity	Wind Strength			
	Force 1 1 – 5 km/h	Force 2 6 – 11 km/h	Force 3 12 – 18 km/h	Force 4 19 – 29 km/h
15%	R = 43 (54) H = 1.0 (1.1)	R = 50 (74) H = 1.1 (1.5)	R = 68 (85) H = 1.4 (1.6)	R = 91 (135) H = 1.7 (2.4)
25%	R = 40 (51) H = 0.9 (1.1)	R = 46 (66) H = 1.0 (1.3)	R = 63 (78) H = 1.2 (1.5)	R = 80 (129) H = 1.5 (2.2)
35%	R = 34 (44) H = 0.8 (0.9)	R = 40 (54) H = 0.9 (1.1)	R = 52 (65) H = 1.1 (1.3)	R = 65 (112) H = 1.3 (2.0)
45%	R = 27 (34) H = 0.7 (0.8)	R = 34 (45) H = 0.8 (1.0)	R = 45 (58) H = 1.0 (1.2)	R = 58 (101) H = 1.2 (1.9)
55%	R = 23 (29) H = 0.6 (0.7)	R = 29 (40) H = 0.7 (0.9)	R = 38 (50) H = 0.9 (1.1)	R = 50 (90) H = 1.1 (1.7)
65%	R = 18 (23) H = 0.6 (0.6)	R = 22 (34) H = 0.6 (0.8)	R = 31 (43) H = 0.8 (1.0)	R = 43 (81) H = 1.0 (1.6)
75%	R = 14 (18) H = 0.5 (0.6)	R = 18 (29) H = 0.6 (0.7)	R = 25 (38) H = 0.7 (0.9)	R = 36 (72) H = 0.9 (1.4)
85%	R = 11 (14) H = 0.4 (0.5)	R = 14 (23) H = 0.5 (0.6)	R = 18 (32) H = 0.6 (0.8)	R = 29 (65) H = 0.7 (1.3)

(4) Fourth Suitable Burning Day After Rain
(Available Fuel = 18 t/ha, Fuel Moisture Content 15–20%)

Relative Humidity	Wind Strength			
	Force 1 1 – 5 km/h	Force 2 6 – 11 km/h	Force 3 12 – 18 km/h	Force 4 19 – 29 km/h
15%	R = 50 (61) H = 1.1 (1.2)	R = 59 (83) H = 1.2 (1.6)	R = 76 (99) H = 1.4 (1.8)	R = 99 (153) H = 1.8 (2.6)
25%	R = 43 (54) H = 0.9 (1.0)	R = 52 (72) H = 1.0 (1.2)	R = 67 (85) H = 1.2 (1.4)	R = 85 (137) H = 1.4 (2.2)
35%	R = 38 (47) H = 0.8 (0.9)	R = 47 (61) H = 0.9 (1.1)	R = 59 (74) H = 1.1 (1.3)	R = 74 (124) H = 1.3 (2.0)
45%	R = 32 (40) H = 0.8 (0.9)	R = 41 (52) H = 0.9 (1.1)	R = 52 (65) H = 1.1 (1.3)	R = 67 (110) H = 1.3 (2.0)
55%	R = 27 (32) H = 0.7 (0.8)	R = 36 (45) H = 0.8 (1.0)	R = 45 (58) H = 1.0 (1.2)	R = 59 (99) H = 1.2 (1.8)
65%	R = 22 (27) H = 0.6 (0.7)	R = 31 (36) H = 0.8 (0.8)	R = 38 (50) H = 0.9 (1.1)	R = 52 (88) H = 1.1 (1.7)
75%	R = 16 (22) H = 0.5 (0.6)	R = 25 (31) H = 0.7 (0.8)	R = 32 (43) H = 0.8 (1.0)	R = 45 (79) H = 1.0 (1.5)
85%	R = 13 (16) H = 0.5 (0.5)	R = 22 (25) H = 0.6 (0.6)	R = 25 (38) H = 0.7 (0.9)	R = 38 (72) H = 0.9 (1.4)

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APPENDIX 1.

Compartment and Logging Area	Fuel Quantities t/ha		Reduction	
	Pre-burn	Post-burn	t/ha	%
Type 1 Fuel				
12 A Kelly	9.68	4.59	5.08	52
17A Kelly	11.83	1.63	10.20	86
16A Kelly	12.86	3.55	9.31	72
18B Kelly	16.82	2.04	14.78	88
18A Kelly	11.53	8.86	2.67	23
44 Elliot	10.97	4.20	6.77	62
45 Elliot	13.15	4.70	8.45	64
49 Kelly	8.78	3.59	5.19	59
3 Dempster	9.29	7.56	1.73	19
1 Dempster	9.60	6.10	3.50	36
12A Dempster	26.16	11.54	14.62	56
Mean	12.79	5.31	7.48	58
Type 2 Fuel				
37 Kelly	18.02	8.53	9.49	53
62 Elliot	7.11	2.89	4.22	59
63 Elliot	7.33	1.33	6.00	82
37 Elliot	9.06	1.21	7.85	87
2 Kelly	13.68	4.43	9.25	68
50 Kelly	11.32	3.74	7.58	67
1 Dempster	13.77	6.58	7.19	52
Mean	11.47	4.10	7.37	64
Type 3 Fuel				
37 Dempster	12.85	5.52	7.33	57
9 Dempster	14.42	4.39	10.03	70
38 Dempster	9.82	2.89	6.93	70
86 Elliot	14.54	5.87	8.67	60
85 Elliot	14.15	3.97	10.18	72
88 Elliot	13.43	7.71	5.72	43
38 Kelly	13.68	7.70	5.98	44
37 Kelly	18.60	5.92	12.68	68
39 Kelly	10.88	4.99	5.89	54
40 Kelly	13.27	12.13	1.14	9
51 Elliot	15.13	5.50	9.63	64
1 Dempster	12.16	2.72	9.44	78
21A Dempster	12.68	6.96	5.72	45
3 Dempster	9.62	2.26	7.36	76
Mean	11.47	4.10	7.37	64
Type 4 Fuel				
3 Dempster	13.81	10.86	2.95	21
2 Kelly	28.00	14.33	13.67	49
4 Dempster	12.68	6.96	5.72	45
Mean	18.16	10.72	7.44	41
			Overall Mean	**56**

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the fire behaviour of type 2 fuels in south Queensland and subsequently the amount of variation between these conditions and other conditions throughout the State. The use of non-linear models is envisaged.

Drying of fuels also needs to be predicted more accurately by the use of non-linear models and, if necessary, the collection of more data.

Fire behaviour of wild fires and the damage caused by such fires need to be further investigated with a view to constructing predictive models for various conditions which can be used as guides for suppression of wild fires. In this way, priorities for treatment of fuels by prescribed burning may be more easily assessed.

Variables which have a major influence on fire behaviour such as fuel quantity and fuel moisture content need to be measured or estimated before prescribed burning a particular area. Modelling of fuel quantity from other variables such as tree spacing, site quality, age of fuel and fuel depth would be a useful further development. A simple, direct measurement of fuel moisture content is also required. The 'Speedy Moisture Meter' should be further tested to fill this demand.

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ABSTRACT

Prescribed burning has become a subsidiary management tool in Queensland exotic pine plantations. The techniques now used were developed by a series of burning trials carried out over a wide range of sites.

Some experimental work has been carried out to investigate relationships between fuel properties, fuel drying and fire behaviour in the plantation environments. The resultant preliminary models need more development.

No short-term effects of low intensity fire on the site and growth factors examined were apparent so long as crown scorch did not occur.

The application of the developed techniques into routine operational practice has been followed. Indications are that plantation prescribed burning is a very useful tool which should be used increasingly as an integral part of the protection system. Concurrently, the effect of repeated burning on site and growth factors should be monitored.

More experimental fire data are needed and further technique trials are recommended.

Using basically the same techniques, exotic pine plantations have been burnt over a wide range of climates from Passchendaele in the south to Cardwell in the north and in a wide range of fuel types (Table 24). This suggests a flexibility in the operation which has not yet been fully determined.

Table 24. Proportion of total area burnt (per cent) 1973 to 1979 by fuel types and sub-district

Fuel Type	Sub-district								Mean
	Beerburrum	Toolara	Tuan	Bundaberg	Rockhampton	Ingham	Yarraman	Warwick	
1	8.5	26.5	12.8	30.3	0.9	55.9	27.8	59.5	27.7
2	37.4	38.0	34.0	47.9	13.2	25.3	17.9	21.4	29.4
3	37.7	32.3	46.8	12.0	63.8	7.8	8.7	8.7	27.2
4	10.2	3.0	3.8	6.6	14.5	11.0	41.5	6.4	12.1
5	6.3	0.2	2.6	3.2	7.5		4.7	4.0	3.6

Because of the flexibility of the operation and the wide range of climatic conditions and fuel types experienced, it is unlikely that a practical burning guide can be developed to cater for all factors. Such a guide would be very cumbersome and impractical in field situations. The simple guide presently in use is the format favoured for future guides. Alterations to the content of this present guide will probably be made in the future as more data are collected.

Indications are that stem growth losses do not occur in the short term when plantation burning is carried out and crown scorch is avoided. To facilitate ongoing evaluation, continued monitoring is required of the effects of prescribed burning on: stem growth in the long term; soil litter and foliar nutrient levels; bark thickness; stem taper and wood damage.

FUTURE DEVELOPMENTS

Prescribed burning in Queensland exotic pine plantations has been developed to a stage where it is generally acknowledged as being successful. Nevertheless further developments of the techniques are necessary.

Ignition from a helicopter is a possible means of facilitating burning within large plantation centres in the face of reduced manpower availability. Burning at other times of the year to that which is presently acceptable, burning at night and burning under drier conditions are possibly partial solutions which have not yet been fully investigated.

The fire behaviour data base needs to be extended to include data from north Queensland plantations, data from fuel types other than type 2 fuels and more data from type 2 fuels in south Queensland. More successful predictive models may then be built up to predict

The only alternative to burning greater areas in a shorter time is to extend the burning season into other months when conditions are less suitable,or to continue burning when fuel conditions become too dry on present standards. Accumulated experience is that burning in other months leads to problems associated with higher temperatures and higher drought indices. Scorch may result when fuel conditions become too dry. The primary objective of scorch-free burns would have to be altered to allow burning under drier conditions.

Table 22. Proportion of total area burnt (per cent) 1973 to 1979 by scorch class and sub-district

Scorch Class	Sub-district								Mean
	Beerburrum	Toolara	Tuan	Bundaberg	Rockhampton	Ingham	Yarraman	Warwick	
1	0.1	2.2	0.7	4.4	1.2	0.7	0.2	0.3	1.2
2	1.6	1.5	2.8	5.9	1.2	2.4	0.2	1.8	2.2
3	98.3	96.3	96.5	89.7	97.6	96.9	99.6	97.9	96.6

Of the 22 000 ha burnt to date, almost 97 per cent has been free of scorch (Table 22), and almost 70 per cent has been burnt 'perfectly' (Table 23). Such figures indicate that plantation burning has been successful even through the development phase. Further improvement is likely now that burning techniques have been developed for most areas and burning experience has been gained by a large number of staff.

Table 23. Proportion of total area burnt (per cent) 1973 to 1979 by burn class and sub-district

Burn Class	Sub-district								Mean
	Beerburrum	Toolara	Tuan	Bundaberg	Rockhampton	Ingham	Yarraman	Warwick	
1	4.7	1.0			2.8	6.3	11.7	4.2	3.8
2	9.1	17.5	16.4		12.9	19.0	15.9	29.4	15.0
3	77.0	74.0	70.1	48.2	77.3	70.0	67.5	65.4	68.7
4	8.2	6.0	13.5	45.3	5.4	4.2	4.9	0.9	11.1
5	0.8	1.4		6.5	1.7	0.5		0.1	1.4

Because of the success of plantation burning as a low cost protection measure, the protection system on each plantation area should be reviewed critically to ascertain if more plantation prescribed burning could be carried out in preference to more expensive operations such as mechanical firebreak maintenance.

INTRODUCTION

Queensland, the second largest state in Australia, lies between latitudes 11° S and 29° S and covers an area of 1 727 522 square kilometres or about 22.5 per cent of the continent. The area of the State north of the Tropic of Capricorn is 932 860 square kilometres or 54 per cent of the whole.

The major exotic pine plantation areas lie on the coastal lowlands, the main species being slash pine (*Pinus elliottii*, Engelm. var. *elliottii*), Caribbean pine (*Pinus caribaea* Mor. var. *hondurensis* (Sénéclauze) Barr. and Golf., *Pinus caribaea* Mor. var. *caribaea*, *Pinus caribaea* Mor. var. *bahamensis* (Griseb.) Barr. and Golf. and loblolly pine (*Pinus taeda* L.). Small areas of radiata pine (*Pinus radiata* D. Don) and patula pine (*Pinus patula* Schl. and Cham.) are planted on the highlands 150 km from the coast (Figure 1).

For management purposes, the forested area of the State under State Government control is divided into 10 districts and 22 sub-districts. The major exotic pine centres lie in districts, the headquarters of which are located in Brisbane, Gympie, Maryborough, Rockhampton and Atherton.

CLIMATE

Queensland has a sub-tropical to tropical climate with annual rainfall ranging from 3750 mm on the north-east coast to 150 mm in the dry south-west corner. Rainfall generally decreases with increasing distance from the coast. On the average, more rain falls during the warmer months of November to April than during the cooler months (Table 1). Annual rainfall is fairly regular in areas close to the eastern coast but there are marked seasonal variations (Luke and McArthur 1978).

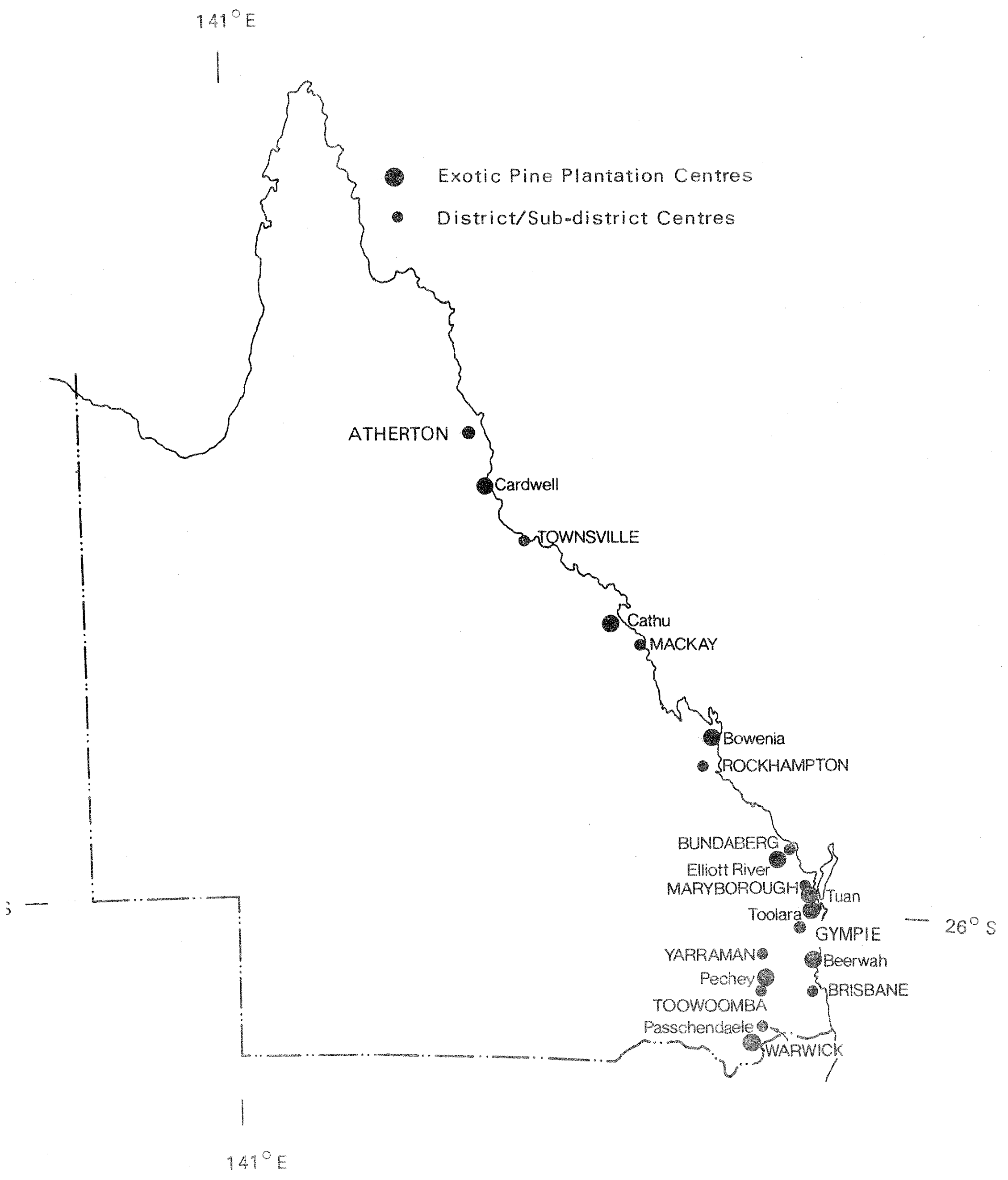
Table 1. Rainfall data from selected Queensland stations

	Cardwell	Yeppoon *	Bundaberg	Beerwah	Passchendaele
Elevation (m)	5.5	10.4	13.7	32.6	914.4
Mean rainfall (mm)					
. May - October	298	334	317	483	328
. November - April	1853	1013	836	1144	495
. Annual	2151	1347	1153	1627	823
Lowest annual	743	179	202	654	430
Highest annual	4088	3973	2847	3307	1484
Mean number of rain days per year	136	106	101	120	102
No. of observations	110	89	98	50	46

Source: Bureau of Meteorology

* *Recording station closest to Bowenia State Forest with long recording history (greater than 40 years)*

Figure 1. Location map



SUCCESS OF DEVELOPED TECHNIQUES

Prescribed burning, through extensive technique trials and experimental fire work, has become an accepted technique for fuel management in exotic pine plantations in Queensland.

A total of 22 000 ha has been burnt since initial large scale trials were started in 1973 (Table 21). Prescribed burning became routine practice in 1976, but the area burnt in a given year has varied considerably according to the prevailing weather conditions. For example, 2360 ha were burnt in a particularly dry year, 1977, compared to 5 970 ha burnt in 1978, a particularly good burning year in most areas. The number of suitable burning days in 1977 was much less than in 1978 and the capacity of the workforce is limited in any area to about 200 ha of burning per day.

Table 21. Annual exotic pine plantation area prescribed burnt by sub-districts

Year	Sub-district								Total
	Beerburrum	Toolara	Tuan	Bundaberg	Rockhampton	Ingham	Yarraman	Warwick	
1973		650.3					30.0		680.3
1974		454.0							454.0
1975	1 401.0	1 340.0	916.5	28.9	370.0				4 056.4
1976	1 118.4	1 030.7	1 174.5	122.1	645.0		77.0		4 167.7
1977	151.0	484.0	107.5	307.1	946.0	29.7	121.0	215.0	2 361.3
1978	1 420.0	1 583.0	1 245.0	274.3	1 031.5	98.0	225.0	95.8	5 972.6
1979	1 195.6	402.2	940.0	-	1 255.2	78.0	238.0	192.5	4 301.5
Total	5 286	5 944.2	4 383.5	732.4	4 247.7	295.7	691.0	503.3	21 993.8

Dry years are also the most fire dangerous years. Therefore, any attempt to increase the burning capacity of the workforce per day would give greater protection in dry years. Because the workforce is generally decreasing in the long term and plantation burning coincides with other important silvicultural operations such as planting, there is a limit to the capacity of the workforce available for manual ignition. Helicopter ignition of plantations appears to be the technique best suited to achieving this increased capacity.

As the large areas of plantation planted in the early 1970s become available for burning in the early 1980s, there will be a need to further increase the amount of burning done to achieve adequate protection at a reasonable price. Helicopter ignition will again be called on to burn the older plantation areas to release the workforce available for manual ignition for the initial burns of the young plantations and difficult older areas or areas with irregular boundaries.

BURN ASSESSMENT

Each burn should be assessed to:

- Evaluate whether the objectives have been achieved.
- Gain information on the reasons for success or failure of the burn
- Gain information for the refinement of techniques and burning guides
- Provide the supervisor of the burn with information on the standard of burn obtained with a given lighting crew using a particular method under certain conditions. This provides re-inforcement for the burning experience of the supervisor in that area.

The overall burn result should be classified by compartments into one of the following burn class types, according to how the burn achieved the fuel reduction objectives without damage:

Burn Class I - Burn too mild. Greater than 30 per cent of area not burnt. Some re-lighting required.

Burn Class II - Burn marginally mild. Reasonable burn results but some unburnt patches. Less than 30 per cent of area not burnt.

Burn Class III - Good burn. Negligible scorch, burn coverage close to 100 per cent, good fuel reduction.

Burn Class IV - Burn marginally hot. Some small patches of scorch on junction zones and edges. Fuel reduction good.

Burn Class V - Burn too hot. Definable areas of scorch. Fuel reduction too high.

Such an assessment of burn success should be combined with a recording of the weather and fuel conditions at the time of the burn so that a data bank of the correlation between burn success, weather conditions and fuel conditions can be built up.

Significant areas of crown scorch should be mapped in the following classes:

Scorch Class I - Severe. Less than 2 m of green crown remaining.

Scorch Class II - Moderate. 2 to 4 m of green crown remaining.

Scorch Class III - Nil. Nil or negligible scorch.

Mapping of scorch classes I and II can be a time consuming ground operation. Small format aerial infra-red photography has shown some promise for distinguishing between scorch types when done by an interpreter with some experience.

In southern Queensland, July and August are the normal winter drought months, September and October bring some storm rains while more dependable storms occur in November and December. The normal wet season occurs during January to March. April to June produce some light rain which has a proportionate greater effect on fuel moisture than summer storms due to less run-off and evaporati losses (Just 1978). In central Queensland rainfall is generally lighter and less reliable except for isolated pockets along the coast which are affected by orographi influences (Hawkins and Muir 1968). In northern Queensland, winter and spring months are usually dry with 70 per cent of the rainfall falling between December an March.

Rainfall in Queensland is mainly derived from monsoons in summer, tropical cyclon and depressions during the period November to April and the south-east trade winds

The most persistent wind influence is the south-east wind. These are usually mois in coastal areas but tend to become drier as they flow over land. Dry winds with a westerly influence are common in central and southern Queensland during late winte and spring. North westerly winds are common during the summer monsoon season i the far north of the State.

High temperatures are common from October to March (Figure 2). High relative humidities are also common during this period. Winters are generally mild in the c areas. The southern interior experiences frequent frosts due to the influence of lo temperatures and dry air during winter.

THE QUEENSLAND FIRE SEASON

Luke and McArthur (1978) describe the fire season in Australia as starting in winter in northern Australia, followed by spring in south Queensland and north New South Wales and summer in southern Australia.

Just (1978) considers the State of Queensland may be split into three distinct regio for the definition of the fire seasons:

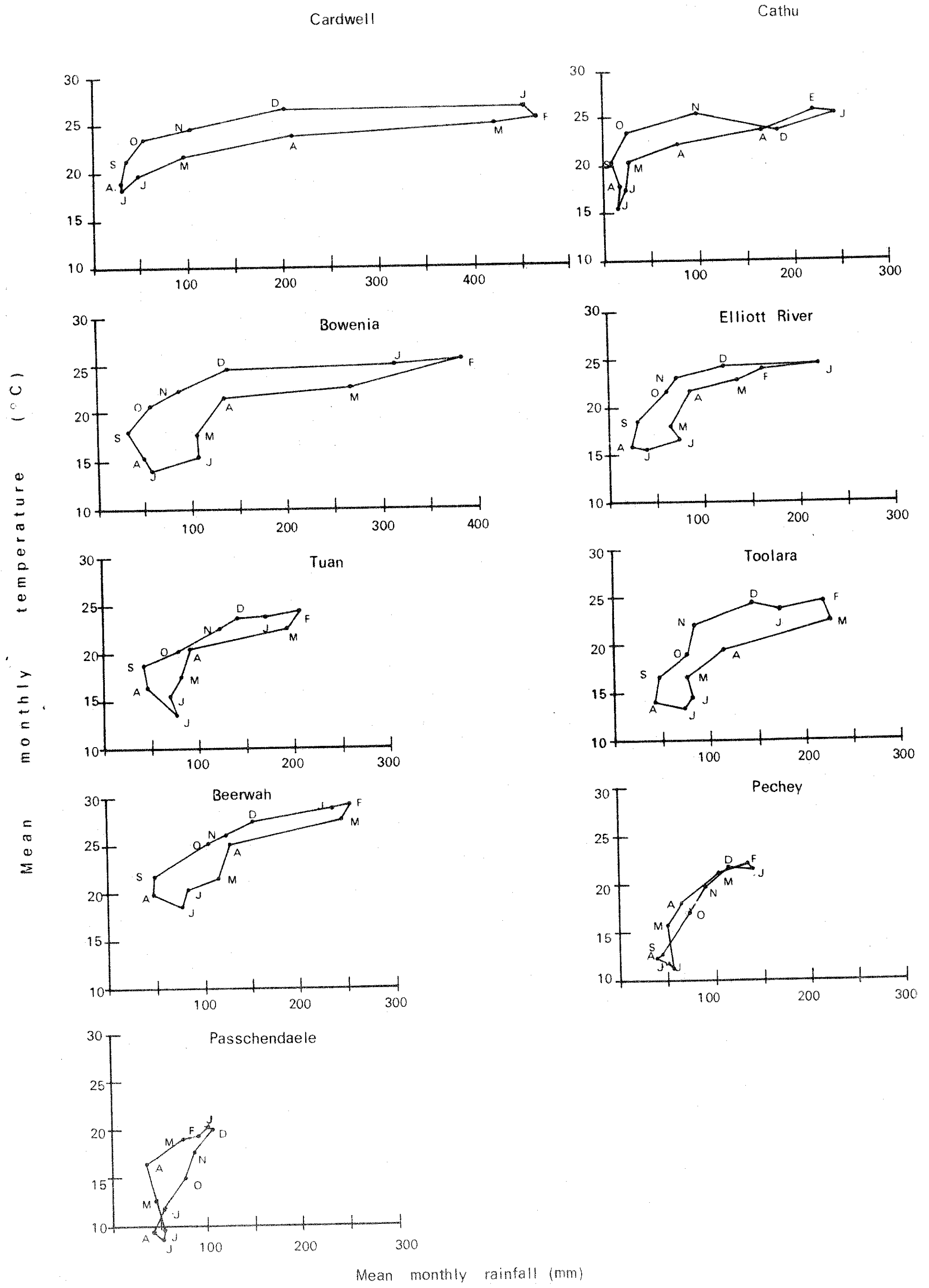
- A north Queensland region, containing Cardwell, Cathu and Bowenia plantation areas has a winter-spring fire season with the normal range of August to November.
- A south Queensland region which includes Elliott River, Tuan, Toolara, Beerwah, Pechey and Passchendaele plantation areas has a spring-summer fire season which extends from September to November and occasionally into December and January.
- A western Queensland region with a spring-summer fire season which extends from October to March.

The monthly distribution of forest fires in eastern Queensland is shown in Figure 3.

Just (1978) argues that fire records indicate a major influence of prolonged drought stress on the incidence of severe fire seasons in south and north Queensland. Sev fire weather which produces a serious fire danger situation can occur in any year, I when it coincides with a bad drought year, the worst fires occur. The 1968 fire se was a serious drought year with some severe fire weather. 440 fires were attendec

Forestry Department personnel in 1968 compared to an average of 184 during the eleven other seasons between 1960 and 1972. A[1] $109 389 was spent on fire-fighting in 1968 compared to $47 579 in 1972/72 and $10 910 in 1969/70.

Figure 2. **Climograms**



[1] *Exchange rate (26/05/80 A$1 = E £ 0.4836*

Aerial ignition

Because of the essential accuracy of the lighting pattern in plantation burning, lighting has usually been done using ground lighting crews with drip torches. The inherent flexibility of helicopters has prompted trials to establish whether lighting could be carried out by dropping incendiary capsules from the helicopter. These trials were contemplated because there is a need for larger areas to be burnt on suitable burning days.

Equipment used in the initial trial was a **Bell 47 Alpine** helicopter and an ignition system utilising small cylindrical plastic vials containing 2.5 grams of potassium permanganate manually injected with 1 ml of ethylene glycol and thrown from the helicopter. The exothermic reaction occurred approximately 25 seconds after injection, thus allowing sufficient time for the vial to fall to the ground before ignition.

Two operators were employed injecting the vials in the helicopter. A further four people were employed as ground crew.

Using a table incorporating ground speed of the helicopter, time lapse between capsule ejection and ground spacing of spot fires the drop interval was established. Flight pattern was marked on the ground using a system of spot fires at the ends of planted rows on one compartment edge. The pilot was then able to align the aircraft to fly along the marked row. Edge lighting of exposed edges was carried out by passing over the edge twice to give a spot fire spacing equal to half the determined spacing for the remainder of the area. Desired ground spacing of spot fires was determined in the usual way using the prescribed burning guide.

The general conclusion reached as a result of the initial trial was that aerial ignition of plantations from a helicopter is a practical alternative to ground ignition in large continuous areas which carry an easily manageable fuel type, provided that some improvements are made to the system used.

The improvements envisaged, at this stage, are:

- The use of an incendiary priming machine instead of the manual injection method.
- Ensuring that the helicopter is aligned on the correct spacing and direction before ignition commences. Turning the helicopter outside the burn area and the use of the longest possible runs should make this possible.
- The provision of an effective communication system between pilot and navigator and navigator and ground crew.

The cost of the operation was twice that of a ground ignition system – A$1.90/ha compared to A$0.95/ha (1978 prices). This cost disadvantage should be lessened by the improvements mentioned. Some cost disadvantage may be able to be accepted if larger areas can be burnt on suitable burning days.

Figure 16. Strip-head fire technique

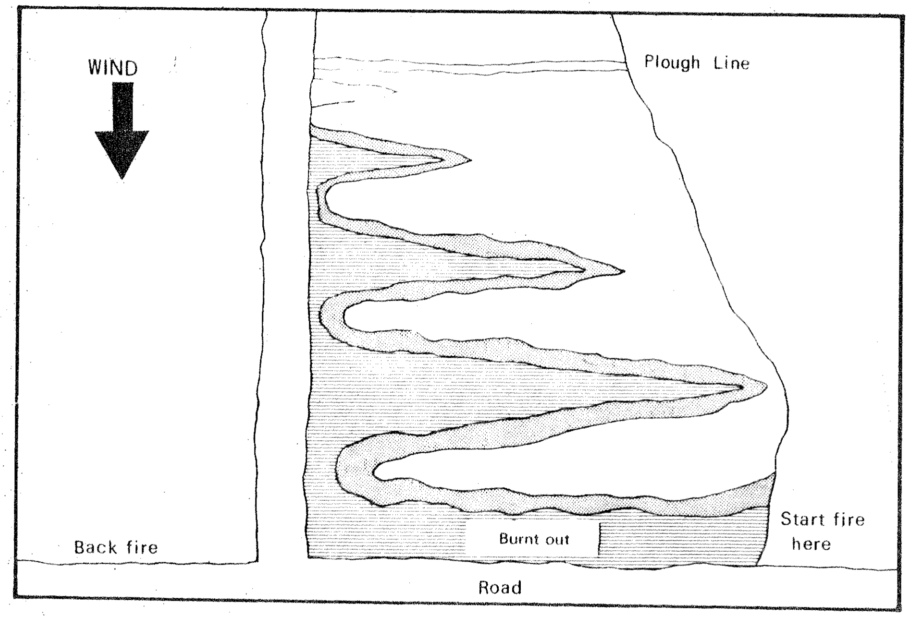


Figure 17. Flank fire technique

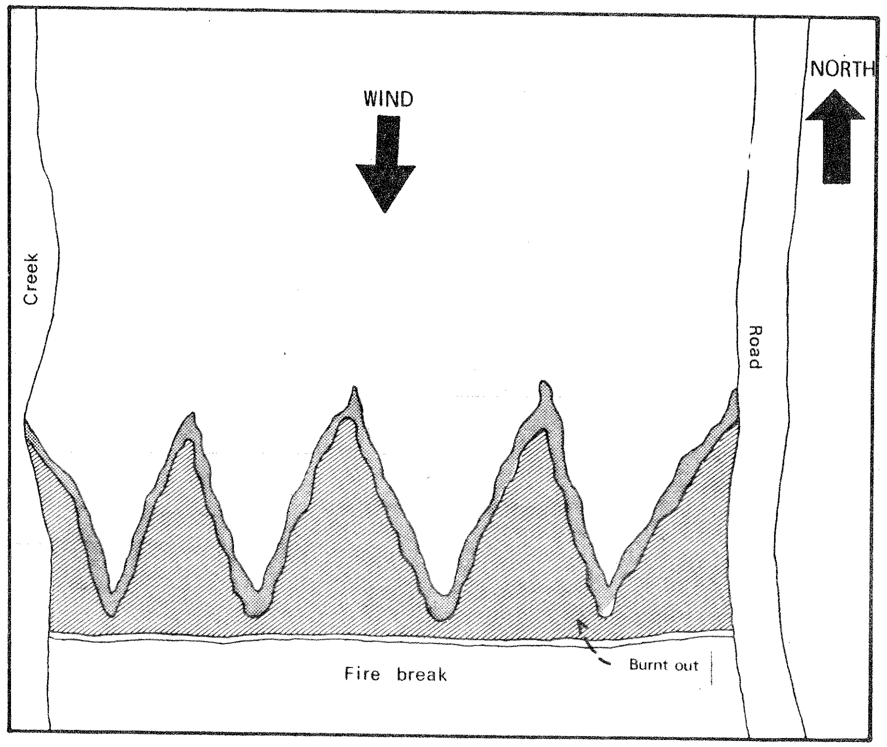
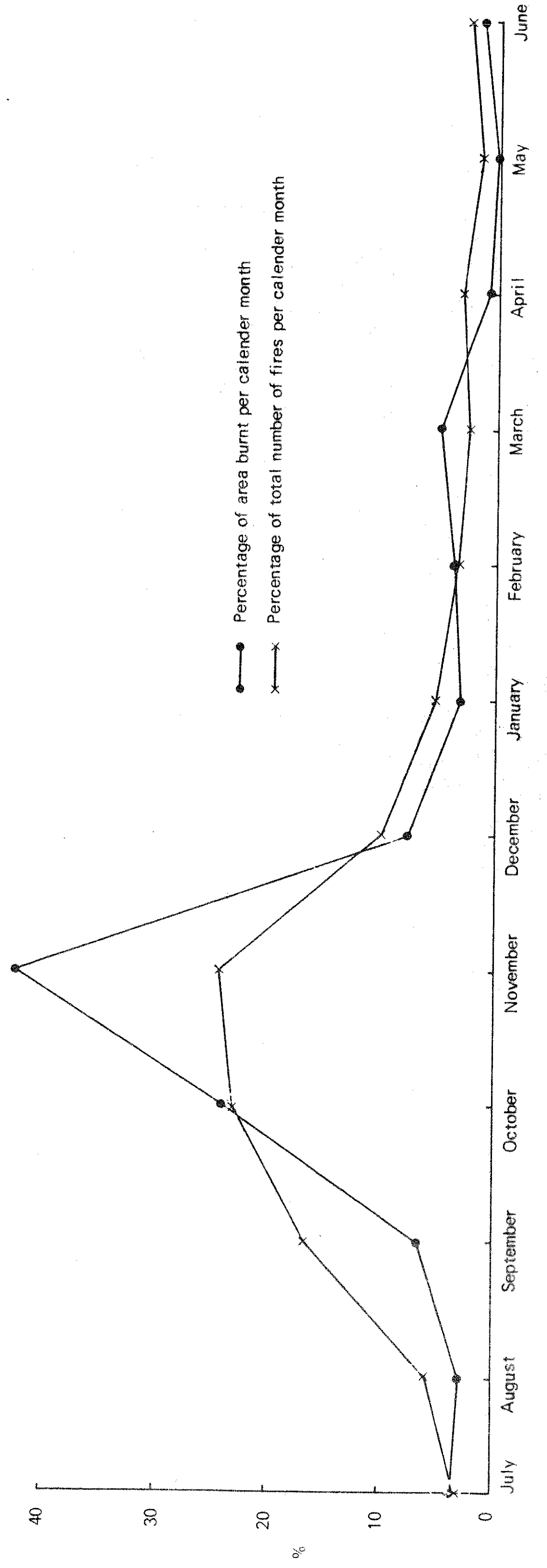


Figure 3. Monthly distribution of forest fires in eastern Queensland 1960-1972



PLANTATION ESTATE

The total area of State Forest planted with exotic pine species to early 1979 was about 77 500 ha, 80 per cent of which are on the coastal lowlands between Brisbane and Bundaberg. The current rate of plantation establishment is from 5000 to 6000 ha annually (Table 2). There are substantial areas of private plantations also, particularly in the south-east.

Table 2. Area of exotic pines planted in Queensland to 31.3.79

	Area by Forestry sub-district (ha)								
	Beerburrum	Toolara	Mary-borough	Bundaberg	Rock-hampton	North Queens-land	Yarraman +	Warwick *	Total
– 1945	1 400	NIL	NIL	NIL	NIL	20		420	
1946 - 50	850	NIL	250	15	30	NIL		175	
1951 - 55	2 075	1 280	1 360	5	560	10	1 400 x	120	
1956 - 60	1 575	1 525	2 025	NIL	830	5	340	450	16 720
1961 - 65	1 020	970	1 055	190	920	5	135	305	4 600
1966 - 70	2 320	3 640	3 310	1 220	980	480	240	420	12 610
1971 - 75	3 580	8 140	7 390	820	880	1 000	440	560	22 810
1976 - 79	2 910	7 100	7 340	630	760	1 380	155	210	20 485
Total	15 730	22 655	22 730	2 880	4 960	2 900	2 710	2 660	77 225
Current Annual Planting	400	1 300	3 000	300	120	500	N.A.	N.A.	

\+ *Includes plantings at Pechey, Esk, Benarkin, Yarraman, Gatton*

* *Includes plantings at Passchendaele, Gambubal, Goomburra*

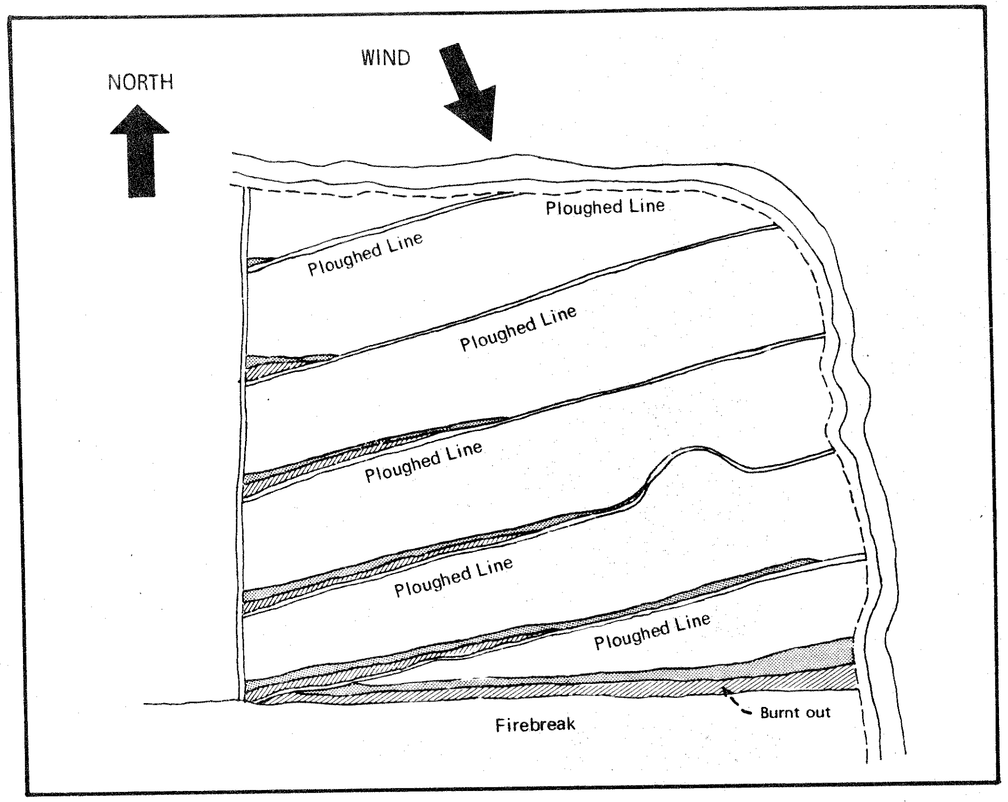
x *Up to 1955*

Source - Queensland Department of Forestry records

The early 1970s saw a rapid expansion in the annual planting, brought about by increased mechanisation of field operations and by the encouragement given by the Australian Government to become self-sufficient in timber supply by the year 2000 through financial agreements. This has resulted in an imbalance of plantation age class distribution such that about 60 per cent of the exotic pine plantation estate is 10 years old or less.

The total standing value of exotic pine plantations in Queensland has been estimated at A$52 million (L.S. Hawkes, unpublished data). Current plantation replacement costs are approximately A$400/ha, excluding overheads. Therefore, the potential exists for massive monetary losses directly from a large plantation fire and, in addition, indirect losses to the timber industry could occur if continuity of timber supply were disrupted.

Figure 15. Strip backfire technique



Other burning techniques

Strip head fire and flank fire techniques are not often used over areas of any size in Queensland. These techniques have some disadvantages for large area burning which preclude their use in most Queensland situations.

The strip head-fire involves lighting a strip of fire, or series of strips on the windward side of a firebreak and at right angles to the wind direction (Figure 16). The strips of fire are spaced such that each fire should not reach high intensity before it meets a firebreak or another strip of fire. This method is only usable when conditions are too damp for grid ignition or fuels are uniform type 2 or type 1 or of low quantity. Large areas of increased fire intensity as fires burn together, known as 'junction zones', are possible with this method. This may be an advantage or a disadvantage depending on the intensity of the individual strip fires and the maximum prescribed fire intensity for the area.

The flank fire technique involves lighting strip fires parallel to the wind direction and into the wind in such a way that most of the area burns with a flank fire (Figure 17). This is often used to supplement a back-fire where the fuels are too light or too moist. The resultant fires are intermediate in intensity between head fires and back fires. A constant wind direction is needed.

- No spot fires are lit any closer to the windward edge than half of the grid interval. On very exposed windward edges the distance to the last spot should be increased to equal the grid interval or greater where necessary.
- The pre-determined grid interval should be adhered to for the whole compartment. It is better to have to re-light an area than to have the grid interval being changed by each lighter depending on how he thinks the fires are burning.
- Knowledge of fuel types occurring in a particular area may necessitate instructing the ignition crew to light some less flammable fuel types more intensively. Prior knowledge of fuel types is therefore, essential. Similarly, the lighting pattern should be flexible enough to allow for one spot fire only to be set in the middle of a large patch of heavy or more flammable fuel in the middle of the area. This is done to ensure that junction zones between fires do not occur in areas of heavy or highly flammable fuel.

The grid ignition system used is, therefore, a mixture of back burning on the edges, and forward, flank and back burning inside the area.

Strip back fire burning

The intention of strip back burning is to set a line of fire along a firebreak so that it burns back into a constant wind (Figure 15). This technique requires a series of parallel firebreaks to be constructed perpendicular to the wind direction and is, therefore, a more expensive method.

The basic advantages of strip back burning are that flame heights are suppressed and some of the heat is dispersed by the wind. It is applicable in situations where the fuel structure is such that flame heights from a forward fire would cause scorch. Young or under-developed plantations with type 3 fuels are examples where this technique can be used. The increase in fire residence time around the tree bases has not caused problems. Plantations as young as age six years can be burnt in this way depending on the tree height development and fuel structure.

Guidelines for use of this method include:

- A wind of constant direction and between 10 and 30 km/hr strength is essential for at least one day. Winds from the south-west in June and July usually fulfil this requirement in coastal Queensland. These occur in high atmospheric pressure systems after the passage of a rain-bearing cold front.
- Fuels must have been fully wet and be drying from the top.
- A series of parallel firebreaks approximately 100 m apart and perpendicular to the anticipated wind direction must be constructed in advance.

EXOTIC PINE PLANTATION WILDFIRE HISTORY

Since the inception of a fire recording system in 1956 a total of 63 exotic pine plantation fires have been attended by Forestry Department personnel, the largest fire covering 245 hectares at Passchendaele in September 1977. Table 3 shows the size distribution of these fires.

Table 3. Size of exotic pine plantation wildfires 1956 to 1978

	Area burnt (ha)				
	0.1	0.1 - 1.0	1.0 - 10.0	10.0 - 100.0	> 100
Number of fires	16	20	16	10	1
Mean fire size (ha)	0.04	0.36	3.25	31.36	245.0

Source - Queensland Department of Forestry records

Table 4 shows that the number of plantation fires is increasing. The mean annual area burnt also appears to be increasing. However, if the large Passchendaele fire is removed from figures the mean annual area burnt for the period 1974 to 1978 is 13.7 ha - a significant decrease from the previous period.

Table 4. Size of exotic pine plantation wildfires occurring during periods shown

	1956-1962	1962-1968	1968-1974	1974-1978
Total area of plantation burnt (ha)	10.2	160.8	133.8	313.6
Mean annual area burnt (ha)	1.7	26.8	22.3	62.7
Number of fires	8	10	15	30
Average fire size (ha)	1.3	16.1	8.9	10.4
Total planted area to end of period (ha)	18 762	27 490	53 240	71 765

A significant increase in the efficiency of the fire protection system in exotic pine plantations is indicated by the fact that the progressively increasing number of fires have not burnt a significantly greater area of plantation even though the total area of plantation is increasing rapidly.

FIRE PROTECTION IN EXOTIC PINE PLANTATIONS

The Queensland Department of Forestry has been engaged in the establishment and management of exotic pine plantations since the late 1920s. The basic fire protection practice has been, until recently, one of complete fire exclusion.

Fire exclusion has been achieved by surrounding plantation areas with cleared and mechanically cultivated firebreaks. The maximum area protected in one unit is 8000 ha. This unit is surrounded by a mechanically cultivated break 60 m wide including a formed road. In the past, this unit was sub-divided further into sub-units of maximum area 2000 ha by 60 m wide planted breaks which were mechanically cultivated between rows. The tendency now is to abandon the planted breaks because of high maintenance costs. Smaller units, called compartments, are a maximum of 150 ha in area and are surrounded by a 15 m wide cultivated break which contains a road. Compartments are further sub-divided by unformed tracks located at intervals of 100 to 150 m.

Plantation areas are planned to include areas of native vegetation for various purposes. The present guidelines allow for retention of approximately 13 per cent of the original vegetation area in the form of viable areas in each of the original vegetation types. When these retained areas are small in size and are not separated from the plantation by tracks, they complicate protection strategies.

Where possible, the protection system of cultivated breaks is supplemented with prescribed burning of native forest bordering the breaks. This burning is made necessary because fire spotting is known to reach 1 km in wildfire situations. The cultivated breaks can be regarded as safety areas for men and equipment and a back-burning line from which to combat wildfires coming from outside the plantation area. In this latter respect, the plantation break system has been generally effective in keeping plantation areas safe from fires originating outside the break system.

The major known sources of plantation wild fires are lightning strikes and human agencies originating within the break system.

Fire detection is achieved by a system of fire towers supplemented by detection from aircraft at times of high fire danger and low visibility.

Expenditure on protection on all State Forests has decreased from 33 per cent of total expenditure twenty years ago to the present figure of around 10 per cent (L.S. Hawkes, unpublished data). One factor contributing to this reduction is the introduction of prescribed burning in most forest types at the expense of complete fire exclusion.

PRESCRIBED BURNING

WHY BURN?

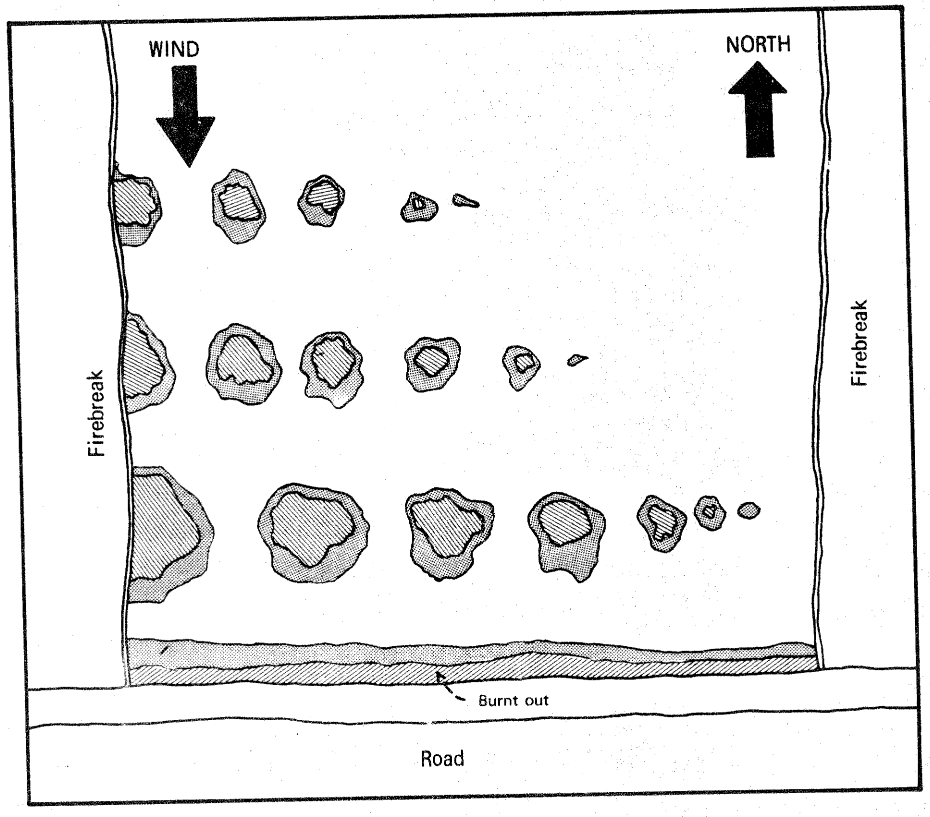
Because of the influence of available fine fuel quantity on fire intensity, it is clear that any reduction of fine fuel quantity over a large area will result in fire outbreaks generally being of lower intensity. Cooper (1975) states that 'unless we are willing to live with the threat of disastrous wildfires, fuel management becomes a must. Without some form of fuel management, wildfires are inevitable'.

- Complete edge burns should be obtained on edges adjoining areas of high risk such as young plantations before the main burn is commenced.

Grid ignition

The basic technique used for burning Queensland exotic pine plantations is grid ignition or, in other words, the lighting of a series of spot fires at a pre-determined square grid spacing (Figure 14). Spacing is calculated in order to permit fires to join up about two hours after ignition. Fire behaviour tables are used to estimate the rate of spread per hour which is doubled to obtain the grid spacing.

Figure 14. Spot fire technique (grid ignition)



An ignition pattern is planned and implemented by application of the following guidelines:

- The leeward edge is lit with spot fires at a spacing equal to the expected rate of spread. This is done early in the day if the leeward edge is exposed.
- The area is spot lit at the pre-determinated spacing along the rows working progressively into the wind.

side of the road is sufficient. Mechanical slashing of grass on the break does not constitute a satisfactory break because the slashed grass is capable of carrying a fire.

Isolation of unplanted areas within compartment boundaries is not essential but is highly desirable especially in situations such as young plantations or buffer strips burnt on a regular basis. Unplanted areas can be burnt successfully but usually not at the same time as the adjacent plantation. Special care needs to be taken in burning these unplanted areas when they are low lying and swampy. It is desirable to maintain the breaks around unplanted areas where these have been constructed, to construct breaks if the plantation forms part of a buffer strip or if the plantation is young or under-developed, and to burn the unplanted area when this is considered safe.

The strip back-burning technique described later requires firebreaks to be constructed within a plantation unit at spacings of approximately 100 m, and around the plantation unit. The alignment of these breaks should be perpendicular to the expected stable wind direction which is usually south-west in most areas. Breaks can be constructed along rows or along previously existing tracks.

Edge burning

Plantation edges are probably the most important sections in a burning operation and are also the most difficult to burn successfully. A number of reasons for this were mentioned previously in this paper.

The nett result of these influences is that edges may burn very fiercely when the rest of the plantation burns with low intensity. The method of burning edges is basically back-burning with fires lit by single spots on the morning of the main fire. A number of rules for edge burning have been established through experience.

- Leeward edges should be spot lit before lighting the main fire. The edge fires should be allowed to join and burn off the edge before lighting the main burn.
- Windward edges should not be lit before the main burn. It should be possible to organise grid ignition so that spot fires will burn out to windward edges.
- Northern edges are usually the driest. These should be lit first on the morning of the burn assuming wind direction is favourable. Western edges should receive second priority. Southern and eastern edges often do not need any special treatment.
- Edges adjacent to 30 or 60 m wide firebreaks or any strips of cleared land should be treated carefully.
- Edge burning, even though it may be done in advance of the main burn, should be done on the day of the main burn. Burning should be able to be organised so that compartments with the most dangerous edges are burnt first.
- Fires lit by single spots should be used at a spacing calculated to give joining of the fires within one hour of lighting.

The most efficient means of fuel management has been shown to be prescribed burning.

Prescribed burning has been defined by Luke and McArthur (1978) as 'the skilful application of fire to natural fuels under conditions of weather, fuel moisture and soil moisture that will allow confinement of the fire to a predetermined area, at rates of spread and intensity appropriate to providing planned benefits with minimum damage at an acceptable cost'.

Results from a study in the southern coastal plains of America, testing the relation between understorey fuel accumulations and wildfires, indicate that the large, destructive wildfires occurred, in almost every case, in heavy fuels where prescribed burning was not practised (Davis and Cooper 1963). McArthur (1962, 1965) notes similar relationships in prescribed burning in Australian eucalypt forests.

Southern pines have been described as being resistant to fire because their cambiums are insulated by thick bark and their crowns can withstand repeated scorching (Sackett 1975). Apart from the thick bark southern pine species have bark with high additional insulating efficiency (Hare 1965).

Prescribed burning has been, and continues to be an effective, inexpensive means of reducing fuel accumulations and, hence, the risk of damage from wildfire (Sackett 1975). Southern pines are fire resistant but wildfire damage and death does occur when fuel accumulations are left unmanaged.

Increasing public usage of plantation areas for recreation and of plantation roads as access for other recreational pursuits means that the potential sources of internal ignition in plantations are increasing rapidly in number. The overall objective of fire prevention must be to prevent the large uncontrollable fires rather than to reduce the total number of fires. Fuel management in depth must be the only method of achieving this objective. Prescribed burning is the most efficient and economical method of managing fuels in depth at this stage.

EFFECTS OF LOW INTENSITY FIRE

The level of fire intensity that can be described as low is the subject of some debate. McArthur (1962) describes 345 kw/m (Table 5) as the upper limit of intensity for acceptable damage. Brown and Davis (1973) list 555 kw/m as being 'probably near the maximum that could be used in prescribed burning work'. It is likely that the maximum fire intensity allowable depends on factors such as species in the overstorey and their height development.

Table 5. Fire intensity limits for acceptable damage standards in commercial forests (ex McArthur (1962))

Fire intensity (kw/m)	Description of fire behaviour
17 to 45	Intensity too low. Fires generally self-extinguishing
46 to 175	Optimum intensity
176 to 240	Too severe for some forest types
241 to 345	Upper limit for acceptable damage effects

The level of fire intensity which will cause damage to a forest depends on the stage of development reached by those stems in the forest which are considered valuable. The level of acceptable fire intensity can, therefore, be related to the height of the dominant stems (Table 6). From the limited amount of data available it would seem that this relationship holds for Queensland exotic pine conditions (Table 7). All of the recorded scorch-free burns fall within the fire intensity and dominant height limits listed.

Table 6. Acceptable prescribed burn intensity related to height of dominants in the stand (all species) (ex R.H. Luke, unpublished data)

Height of dominants (m)	Acceptable fire intensity (kw/m)
10.0	115
15.0	170
20.0	230
25.0	285
30.0	340

Table 7. Scorch-free burns in Queensland exotic pine plantations

Predominant height of stand (m)	Fire intensity (kw/m)	Predominant height of stand (m)	Fire intensity (kw/m)
19.8	69	19.8	27
18.7	48	19.9	30
18.1	118	19.0	76
21.0	38	20.4	89
24.1	83	19.6	39
23.0	217	18.1	135
23.7	24	18.8	121
25.7	131	19.1	31
15.0	157	18.1	28
15.1	160	16.4	76
14.8	148	16.4	135
17.4	102	15.3	149
18.2	117	16.0	97
17.4	58		
17.8	48		
17.9	117		

Selection of areas for prescribed burning is done along the following lines:

- In large plantation areas parallel buffer strips are selected for burning on a rotation of three years.
- In smaller areas such as Bowenia and Cathu, the whole area may be burnt regularly or at least once during a rotation.
- Compartments adjacent to major access roads are burnt so that, where possible, fuels are kept to less than two years old.
- External firebreaks are strengthened by the burning of adjacent compartments. Mechanical maintenance of the firebreak may be avoided during the year that adjacent compartments are burnt.
- Areas may be selected for specific purposes such as improvement of access, reduction of thinning debris fuel, decreasing risk around included areas to be planted, seed collection, and protection of temporary risk areas.

Areas that should be avoided during burning include:

- Compartments containing experiments which are not to be burnt.
- Compartments underplanted with hoop pine (*Araucaria cunninghamii* Ait. ex D. Don).
- Compartments containing significant areas of poor stocking, low site index or failed plantation.
- Areas which would be difficult or expensive to isolate from adjoining young plantations or swampy areas.
- Areas of a fuel type which is difficult to burn except where there is an urgent requirement to reduce fuels in such areas.

Prescribed burning of plantations should be considered an integral part of the protection system. It should be used, wherever possible, as the most efficient means of fuel reduction integrated with other protection measures.

TECHNIQUES

Various burning techniques are available to accomplish specific burn objectives under different weather, topographic and fuel conditions.

Firebreak preparation

"Confinement of the fire to a predetermined area" is an essential part of Luke and McArthur's (1978) definition of prescribed burning. To achieve this a break free of any flammable fuel must be constructed around the compartment or group of compartments to be burnt at one time. Normal road maintenance is sometimes used to achieve this. If road maintenance is not planned a single sweep of a grader along the fire

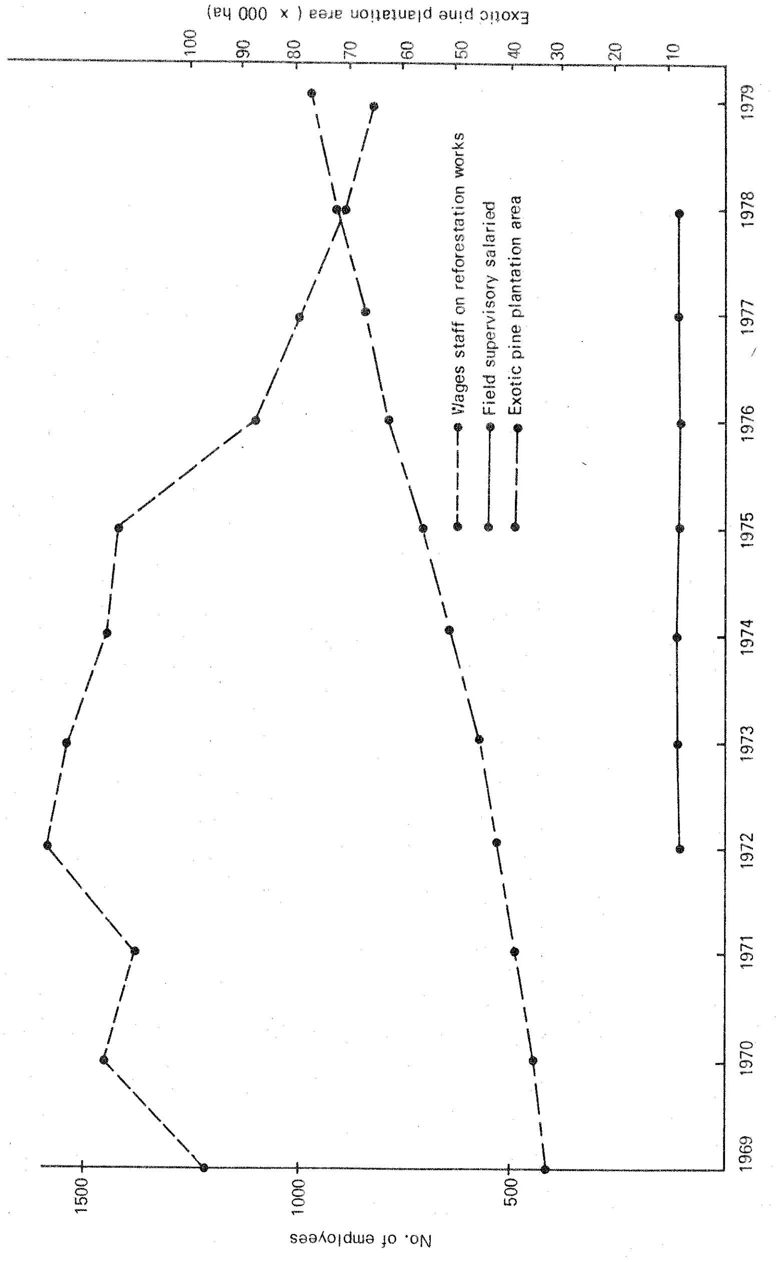


Figure 13. Number of employees and total exotic pine plantation area 1969/79 (ex L.S. Hawkes, unpublished data)

A more convenient method of prescribing fire intensities for a particular stand is that used in the prescribed burning guide developed for Queensland forest conditions, of flame heights for particular plantation ages and site indices.

Any prescription must be based on the maximum air temperatures likely during the burning season. The quantity of heat required to raise the temperature of living vegetation to the lethal temperature is directly proportional to the difference between this temperature and the initial vegetation temperature. Hence fires of equal intensity are more damaging on hot days than on cool days (Byram 1958).

Plantation Growth

Stand increment

The effect of low intensity fire on growth of the plantation crop has been investigated on four separate sites at Toolara and Tuan State Forests since 1967. Investigations are continuing on one of these sites at Tuan State Forest.

All of these experiments have shown that, during normal rainfall years, plantation prescribed burning without crown scorch has no significant effect on plantation growth.

Analysis of variance shows that no significant differences occur between the mean basal area, mean predominant height and mean total volume increments on burnt and unburnt plots (Table 8).

Table 8. Increment data by increment periods from four prescribed burning experiments in slash pine plantations

A) Experiment 36 Fire, Compartment 6A Tahiti Logging Area Tuan State Forest - burnt June 1972, June 1975, June 1978

	Increment period						
	5/72 - 5/73	5/73 - 5/74	5/74 - 5/75	5/75 - 5/76	5/76 - 5/77	5/77 - 5/78	5/78 - 5/79
Rainfall (mm)	1364	2134	1339	1961	1226	862	1194
Decile value	6	9	6	9	5	1	4
Mean basal area increment (m^2/ha)							
- Burnt plots	2.35	2.56	1.59	1.73	1.28	0.33	0.92
- Unburnt plots	2.18	2.63	1.44	1.71	1.33	0.39	1.18
Significance	N.S.	N.S.	N.S.	N.S	N.S.	N.S.	N.S.
Mean total volume increment (m^3/ha)							
- Burnt plots	21.871	29.191	17.455	20.401	16.502	6.120	9.777
- Unburnt plots	19.910	27.279	16.703	21.273	16.144	7.171	11.570
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Predominant height increment (m)							
- Burnt plots	0.9	1.1	0.7	0.9	0.8	0.3	0.3
- Unburnt plots	0.8	1.0	0.9	1.0	0.7	0.4	0.2
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 8. (cont'd)

B) **Experiment 3 Fire, Compartment 1 Dempster Logging Area Toolara State Forest - burnt May 1967, June 1972, June 1975**

	5/67 - 5/68	5/68 - 5/69	5/69 - 5/70	5/70 -5/71	5/71 -5/72	5/72 -5/73	5/73 -5/74	5/74 - 5/75	5/75 -5/76	5/76 -5/77
Rainfall (mm)	2153	658	1582	1813	1728	1458	2378	1250	1701	913
Decile value	9	1	7	9	8	7	9	5	8	1
Mean basal area increment (m^2/ha)										
- Burnt plots	1.97	0.43	1.23	1.52	1.56	1.48	1.13	1.12	1.51	1.81
- Unburnt plots	2.25	0.61	1.38	1.41	1.65	1.54	1.21	1.24	1.46	0.85
Significance	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

C) **Experiment 32 Fire, Compartment 64 Elliot Logging Area Toolara State Forest - burnt June 1971**

	5/71 -5/72		**5/72 - 5/73**		**5/73 - 5/74**		**5/74 - 5/75**
Mean basal area increment (m^2/ha)							
- Burnt plots	2.69		2.06		2.29		1.46
- Unburnt plots	2.63		1.76		2.34		1.77
Significance	N.S.		N.S.		N.S.		N.S.

D) **Experiment 33 Fire, Compartment 46 Elliot Logging Area Toolara State Forest - burnt June 1971**

	5/71 - 5/72		5/72 -5/73		5/75 -5/76
Mean basal area increment (m^2/ha)					
- Burnt plots	2.05		1.75		1.73
- Unburnt plots	1.91		1.71		1.76
Significance	N.S.		N.S.		N.S.

Small isolated plantations outside of the overall plantation protection system present fire protection problems because of their isolation from manned forest reserves, the high firebreak maintenance cost per unit area planted and the lack of protection outside the firebreak system. In such cases, prescribed burning of the whole area on a three-year rotation facilitates less expensive protection.

The 60 m wide mechanically cultivated external firebreak systems around plantations do have some 'weak links' where maintenance is difficult and expensive. Swampy areas and rocky areas are examples of this problem. The weak links can be strengthened by prescribed burning of adjacent plantation compartments.

Expensive mechanical maintenance of external and internal firebreaks can be reduced by prescribed burning of adjacent compartments.

Silvicultural benefits

The development of mechanical site preparation techniques has meant that low lying areas which were previously classified as unplantable can now be cleared and planted. These areas are often included within older plantation areas. Prescribed burning of the surrounding older plantations allows burning of the cleared and stacked vegetation to be done under more suitable conditions, thus ensuring complete removal of all cleared vegetation. Cost savings ensue in the later site preparation and tending operations.

Removal of part of the plantation understorey by prescribed burning can improve access for silvicultural operations such as thinning.

Prescribed burning of seed orchards and some seed production areas reduces the depth of suspended litter, thereby decreasing the time taken in searching for cones dropped to the ground by pickers during seed collection.

Minimising risk in specific areas

Increasing public usage of plantation areas means that plantations adjoining popular access roads and popular recreation areas are being subjected to an increasing fire risk. This risk can be minimised by regular fuel reduction. Compartments on opposite sides of popular access roads can be burnt alternately. Compartment-wide strips around popular recreation areas can be burnt in alternate years.

Prescribed burning may be used to decrease the temporarily high fire risk associated with activities such as road construction, periods of high visitor usage and timber extraction.

SELECTION OF AREAS FOR PRESCRIBED BURNING

Areas could be selected for prescribed burning to fulfil any of the preceding benefits. The basic principle of selection must be the achievement of the maximum protection benefit from the money spent in doing the burning.

Increasing plantation area combined with decreasing total workforce make plantation protection from fire an increasingly important operation (Figure 13). Prescribed burning is playing an important role in the fire protection practice in Queensland plantations and, therefore, is increasing in extent. Selection of areas for burning to achieve maximum protection benefit should become even more important in the future.

Type 1 fuels were used as the basis of the drying tables. The compact litter layer of type 1 fuels make these fuels the slowest drying. Allowances have to be made for differences in fuel type and differences in amount of exposure.

FIRE BEHAVIOUR

Using data from experimental fires in Queensland and supplementing this data with work done elsewhere, a series of fire behaviour tables have been developed. These tables are based on data from an average fuel type, namely table 2 fuels. Extrapolation to other fuel types can be done in qualitative terms only, until more data are obtained.

It is sufficient for practical burning purposes to be able to say that fuels can be ranked from type 4 to type 1 in decreasing order of fire intensity. Hence, if the fire behaviour of type 2 fuels can be predicted with some accuracy, fire behaviour in other fuels can be approximated.

If fire behaviour variables such as rate of spread and flame height can be estimated, decisions can be made on the stage of development of plantation required and on the spacing of spot fires.

BURNING TECHNIQUES DEVELOPED

MANAGEMENT OBJECTIVES

The over-riding objective for prescribed burning in exotic pine plantations is to reduce ground fuels over a large enough area so that the likelihood of wildfires starting is decreased and the intensity of any wildfires which do start is reduced. Consequently, wildfire control should be easier and damage levels reduced.

The intensity of the prescribed fire should be kept as low as is consistent with the desired fuel consumption. The intention of a prescribed burn is to remove only a proportion of the total litter. It is likely that the amount of litter left after prescribed burning operations in Queensland exotic pine plantations is sufficient to keep surface run-off and soil loss to a minimum. Disruption to microbial activity in the lower litter layers is also likely to be kept to a minimum by retention of part of the litter layer.

Other benefits in addition to fuel reduction accrue from prescribed burning.

Maximum protection benefit

In large plantation areas it is neither feasible nor desirable to reduce fuels over the whole area regularly. The alternative is to carry out fuel reduction burning regularly over smaller strips of strategically placed plantation to give the maximum fire protection benefit from the area burnt. Such a system is known as 'buffer strip burning'. Buffer strips are planned to give the maximum length of burnt area per unit area burnt by selecting narrow compartments where possible. The strips are located in groups of three so that nearby strips can be burnt in successive years on a rotation of three years.

Mean basal area increment was then plotted for each increment period against the standing basal area at the beginning of the period (Figures 4 and 5) for one experimental area. Regressions of basal area increment against basal area for burnt and unburnt plots were tested for common slope and level. All burnt and unburnt regression lines were the same except in 1968/69, a severe drought year. Therefore, the regressions for burnt and unburnt plots for all years, except 1968/69, were pooled to give the lines shown in Figures 4 and 5.

Figure 4. Standing basal area and basal area increment after one burn in 196 on four burnt plots, four unburnt plots and one scorched plot

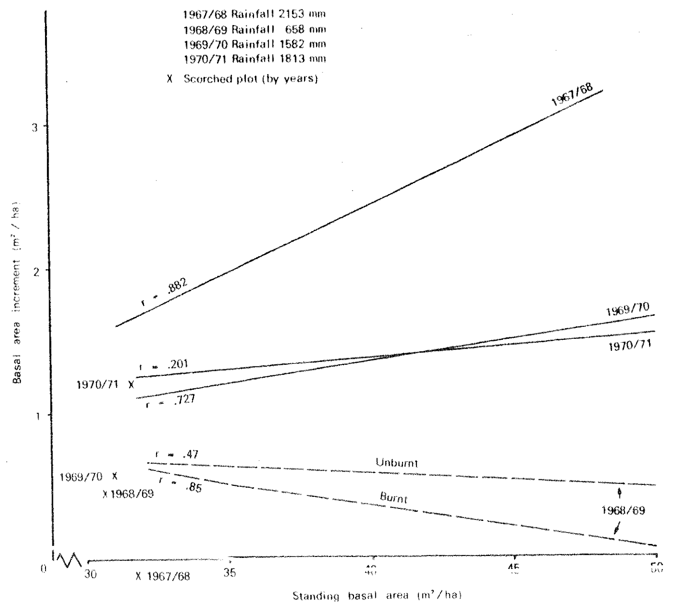
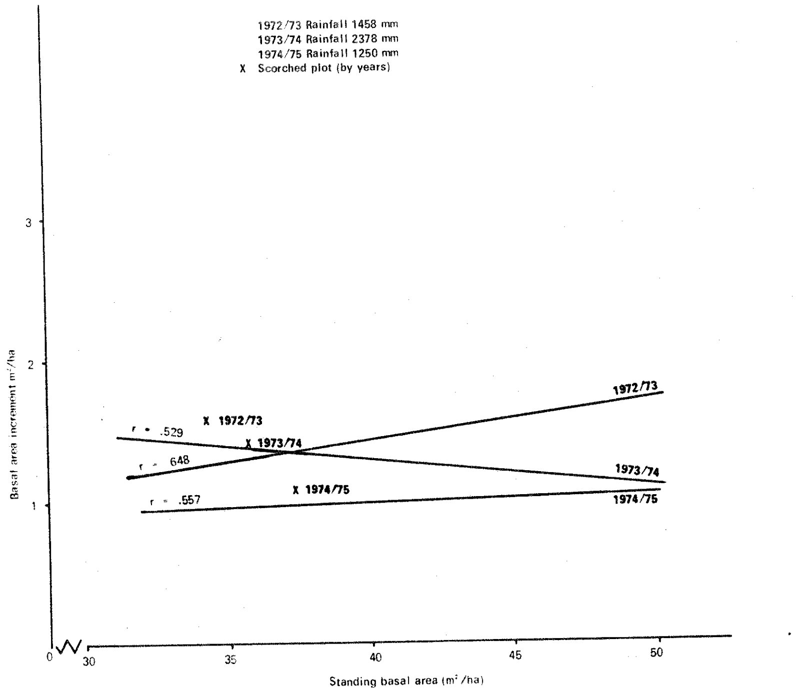


Figure 5. Standing basal area and basal area increment after two burns in 1967 and 1972 on the same burnt and unburnt plots as in Figure 4.



In 1968/69, the burnt and unburnt plot regressions were significantly different at the 5 per cent level, thus indicating that burning can suppress basal area increment in a drought year. The reason for this could be related to the removal of part of the litter in the fire, thereby reducing the moisture retention capacity of the litter layer to such an extent that additional moisture stress led to a reduction in basal area increment on the burnt plots. This effect does not appear to persist when the rainfall returns to normal.

There are, however, no significant differences between the regression lines for burnt and unburnt plots in all experiments when basal area increment is plotted against the rainfall decile value for the period between measures (Figure 6). This indicates that the drought effect on increment after burning is not consistent over all sites. It appears that the drought effect on burnt plots is restricted to areas carrying basal areas greater than 32 m²/ha.

Severe scorching on one plot in this experiment caused by a fire of 420 kw/m intensity depressed the basal area increment until 1973 (Figures 4 and 5). During the period 1967 to 1973 the periodic annual increment on the scorched plot was 0.88 m²/ha compared to a mean of 1.42 m²/ha on all other plots. This represents a total growth loss of 2.26 years increment spread over five growing seasons.

slow to dry. Usually these types occur in small areas associated with fuel types 1, 2 and sometimes 3. The type 5 fuels generally remain unburnt. Intense lighting will usually cause the ground fuels to partly burn. Flaring regularly occurs in the 'ladder fuels' sometimes leading to crown scorch in the pine overstorey.

Fuel characteristics cause differences in fire behaviour which are difficult to quantify. The approach taken in Queensland exotic pine plantations has been to quantify fire behaviour for a particular fuel type, namely type 2 fuels. Differences in fire behaviour between fuel type 2 and the other types are described in qualitative terms.

Definition of the fuel types implies that the descriptions be applied on a broad area basis. Broad area changes in understorey composition and density are required to cause differences in fire behaviour characteristics during a prescribed fire. However, it is essential that all obvious changes in fuel characteristics are known before lighting a prescribed fire. Fuel type maps are prepared, where necessary, for this purpose.

FLAME HEIGHT PRESCRIPTION

A fundamental objective in the use of prescribed fire in plantations is to obtain a satisfactory level of fuel reduction without any crown scorch. Therefore, a maximum fire intensity should be determined for each plantation unit to be burnt if scorch is to be avoided. Scorch is primarily a function of flame height and height to green crown. Height to green crown can be specified in terms of site quality and plantation age. Scorch height and flame height are correlated. Therefore, it is possible to prescribe maximum flame heights for treatment of plantations of various ages and site qualities as has been previously discussed in this paper.

DRYING OF FUELS

For successful fuel reduction burning, sufficient fuel should be dry enough to burn so that fuel reduction of at least 50 per cent over a broad area can be achieved. Fuels should not be so dry that the whole fuel layer is removed.

Burning should not be attempted unless:

- The Drought Index is less than 200.
- At least 7 mm of rain has fallen on the burn site so that the fuel layer is drying from the top down.
- Soil in contact with the litter layer is moist.
- The litter layer feels dry on the top and wet on the bottom.

The rate at which litter fuels dry depends on temperature and relative humidity, wind velocity and exposure to direct sunlight. The moisture content of fuel at any time and hence the quantity of fuel available for burning at that time depends on the factors affecting drying and the time since known amounts of rainfall.

The number of days since known amounts of rainfall and the mean daily maximum temperature during the drying period have been used in the burning guide to estimate the amount of fuel available for burning and, indirectly, the moisture content of the top centimetre of the fuel layer. These factors are then used as a basis for estimating fire behaviour.

Fuel weights are often greater than 18 t/ha. This fuel type often becomes invaded with passion vine (*Passiflora* spp.), couch grass (*Cynodon dactylon* (L) Pers.), and mesic understorey plants such as *Smilax* and *Austromyrtus* spp. These tend to delay drying even further and form a green blanket over the fuel thus leaving unburnt patches.

- **Fuel Type 2.** Fuel suspension caused by understorey species on between 50 and 80 per cent of the area.

  Suspension depth lies in the range 15 to 45 cm. Fuel weights range from 10 to 20 t/ha, the lower values being associated with kangaroo grass (*Themeda australis* (R. Br) Stapf.) and the higher values with grass tree. Drying of the fuel is fairly rapid especially when the understorey species causing suspension are grasses occurring on exposed ridge sites. The fire behaviour of this fuel type is relatively uniform, although some flaring may occur in the suspended fuels.

- **Fuel Type 3.** Fuel suspension caused by understorey species occurring on more than 80 per cent of the area.

  Suspension can be caused by grass trees, sedges and grasses. Fuel depths average about 45 cm with some reaching 100 cm in depth. Drying rates are variable. Fuels with sedges as the suspending species dry rapidly because of the free movement of air through the fuel layer. Dense grass tree fuels tend to be shaded more heavily in the lower layers and less fuel is suspended, thus causing the whole fuel layer to dry more slowly. Problems are experienced in burning these types due to the variable drying rates, flaring, especially in the sedge sub-types, and the frequent association of the sedge sub-types with low lying areas of low site index. Wind influences fire behaviour markedly in these types. Fuel quantity is variable but is usually greater than in other fuel types. Fuel consumption is generally high when the fuels are dry enough to burn because a large proportion of the fuel is suspended.

- **Fuel Type 4.** Dense understorey of blady grass and/or bracken fern occurs over 80 per cent or more of the area.

  This type occurs on plantation edges, in failed areas or in areas of low site index where light conditions are favourable for the development of the above species. The fuel dries rapidly and is prone to flaring particularly on edges subject to the influence of winds. Fire behaviour in this type can be intense in conditions when associated fuel types 1 and 2 will barely carry a fire.

- **Fuel Type 5.** This type can best be described as a type 3 fuel with an intermediate stratum one to five metres tall, causing some of the suspension.

  Pine needle fuel suspended in this intermediate stratum forms 'ladder fuels'. Many species cause this suspension e.g. *Baeckea* spp., *Leptospermum* spp., *Lantana* spp., *Casuarina* spp., *Lepidosperma* spp. Ground fuel quantities are low because of the large amount of fuel suspended. Heavy shading causes the ground fuels to be very

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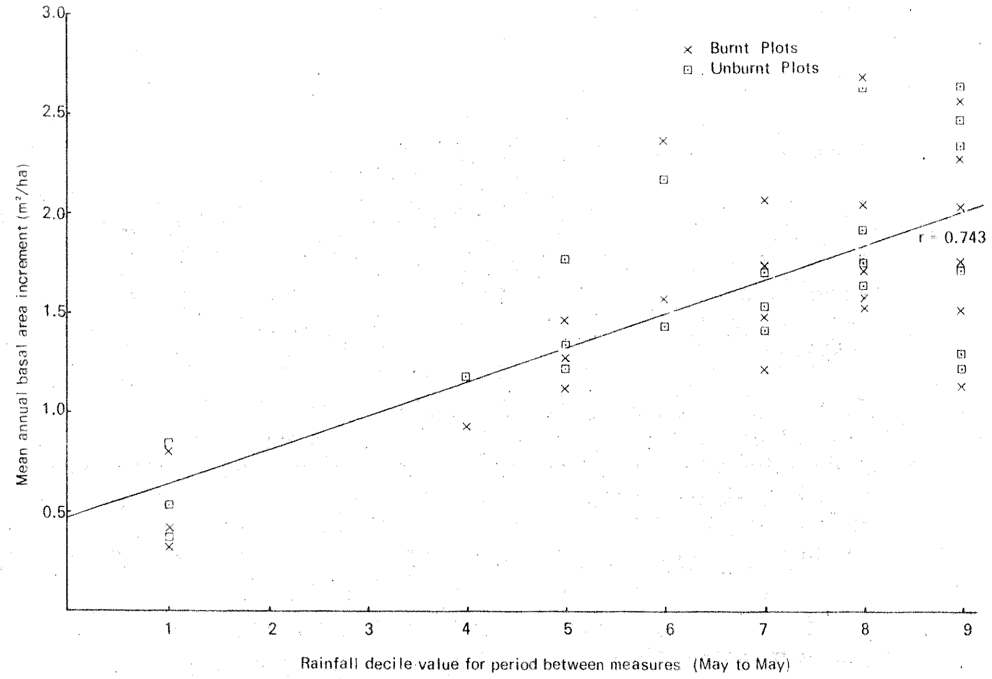
Figure 6. Mean annual basal area increment against rainfall decile values for periods between measures (May to May) from four prescribed burning experiments in slash pine plantations



Bark thickness

On one experimental area bark thickness of all select stems in plots was measured with a standard bark gauge by measuring the bark thickness at the four cardinal points of the compass on each select tree at two heights - 1.5 m and 4.5 m above the ground. Measurements were taken before the first fire in June 1967 and again 12 months later (Table 9).

Table 9. Bark thickness of select stems on four plots burnt in June 1967 and on four unburnt plots

	No. of stems	Mean bark thickness (mm)					
		1.5 m		4.5 m		Increase 1967/68	
		1967	1968	1967	1968	1.5 m	4.5 m
Unburnt	45	19.4	17.6	13.0	11.4	-1.8	-1.6
Burnt	58	17.8	18.0	12.7	12.4	0.2	-0.3

The decrease in bark thickness in unburnt stems is difficult to explain when normally bark thickness increases slightly. Similarly, the changes in bark thickness in burnt plots is contrary to expectations and to that reported by Love (1973) who used a similar bark measuring technique.

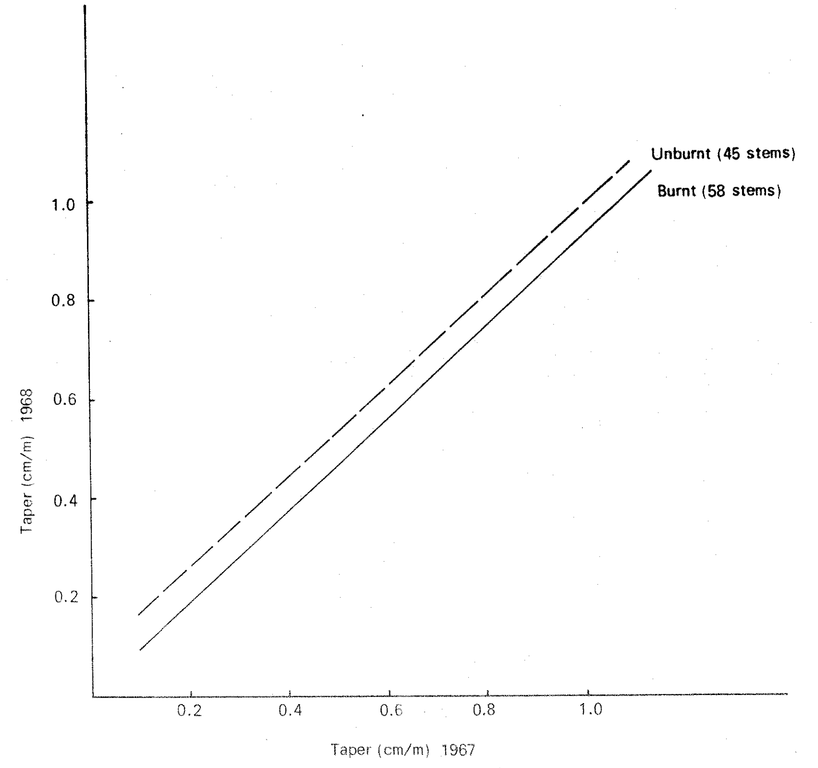
Further bark thickness sampling is intended to investigate the bark thickness variations in more detail.

Stem taper

In the experimental area used for bark thickness measurements, select stems in the burnt and unburnt plots were also used to measure stem taper between the 1.5 m and 4.5 m heights. Stem taper is defined as the mean decrease in stem diameter over bark per metre between two heights on the stem, in this case 1.5 m and 4.5 m.

Figure 7 gives the regression lines of taper before and after the fire on the burnt and unburnt plots. The two regressions are highly significant and the lines have the same slope but different intercepts. The taper difference between the burnt and unburnt stems which exists before the fire has, therefore, been accepted as perpetuating after the fire. Site or planting stock differences could be the reason for this taper difference.

Figure 7. Select stem taper before and after fire in June 1967 on four burnt and four unburnt plots



Fires set in a strip to burn against a wind under the above conditions will spread at the rate of 20 to 30 m/hr. Flame heights will vary according to the fuel type and wind strength.

Ploughed lines set approximately 100 m apart are used as control lines for these fires. At the above spread rates, fires will take three to five hours to burn out. This long burn-out time necessitates stable wind conditions because any shift in wind direction can cause long lines of fire front.

BURNING GUIDE

A burning guide (Appendix 2) has been produced containing information on:

- Drying of fuels under various daily maximum temperatures and rainfall conditions.
- Fire behaviour under various fuel moisture contents, wind strengths and relative humidities.
- Fuel types, lighting techniques, recommended maximum flame heights for various stages of development of plantation and average daily maximum temperatures by months and regions.

This burning guide is based on information obtained from experimental fires on a restricted range of fuels and over a restricted range of conditions. It is meant, therefore, to be a guide only and in this capacity is a useful means of estimating when fuels will become available for burning and what fire behaviour could be expected under certain conditions.

FUEL TYPES

Five fuel types have been defined, based on the structural characteristics of the fuel. The characteristics used are the percentage of area carrying suspended fuel, the average depth of suspension and the species composition of the associated understorey vegetation.

The fuel types developed are:

- **Fuel Type 1.** Fuel suspension caused by understorey species occurs on less than 50 per cent of the area.

  The fuel consists of a continuous fuel layer of compacted litter over greater than 50 per cent of the area. Fire behaviour is very uniform. The upper parts of the litter layer tend to dry out quickly but the lower parts are insulated partly from drying by the compacted litter. It is possible to obtain a 100 per cent burn coverage of these fuels while removing only 20 to 30 per cent of the fuel quantity.

FIRE BEHAVIOUR

Spot fires

Thirty-eight experimental fires have been run in slash pine fuels at Toolara State Forest from 1967 to 1974. Flame heights and fire rates of spread were measured together with meteorological variables such as temperature, relative humidity and wind speed, and fuel variables such as fine fuel quantity consumed by the fire and moisture content of the top of the fuel layer.

Fire behaviour tables were constructed in 1974 using fire behaviour information from similar fuel types in other States, particularly Western Australia, adapted to fit the information gathered in Queensland. The resultant tables are in the prescribed burning guide (Appendix 2).

Complete fire behaviour predictive models based solely on information from Queensland are not possible until more fire behaviour data are collected under Queensland exotic pine plantation conditions. The fire behaviour tables in the prescribed burning guide give a reasonably accurate guide to fire behaviour expected under specified conditions in southern Queensland. As such these tables are a very useful tool for prescribed burning in southern Queensland.

The higher temperatures experienced in central and northern Queensland probably increase fire intensity for the same fuel moisture conditions in southern Queensland. There is need, therefore, to introduce a temperature factor into the fire behaviour tables. This is not yet possible because the temperatures sampled in southern Queensland cover the narrow range of 15° C to 25° C with a concentration of data in the 18° C to 22° C range. Experimental fires will be run in northern Queensland during 1980 to increase the range of temperatures sampled. Further experimental fires will also be run in southern Queensland to broaden the data base and, hopefully, to permit more successful modelling of fire behaviour in pine plantation fuel types.

Strip back fires

Strip back fire burning is a useful burning technique in areas where fuel types or exposure of fuels are likely to cause excessive flame heights. The technique is particularly useful for establishing a series of buffer strips in young plantations.

The conditions necessary for strip back burning have been established by trial burning work under a range of conditions. The necessary conditions may be summarised as:

- Suspended fuels are required.
- Fuels completely saturated by rain one or two days previous to burning.
- Low drought index (less than 100).
- Constant wind from a constant direction and likely to remain constant for at least one day. Such wind conditions often follow the passage of a rain-bearing cold front, the winds being from the south-west. Winds should be of Beaufort Scale Force 2 or greater.
- Topography needs to be fairly flat. Broken topography can cause undesirable wind changes when prevailing wind is constant.

Wood Characteristics

Nicholls and Cheney (1974) concluded that fires of intensity less than 200 kw/m burning under conditions of low drought index were unlikely to cause significant damage to a radiata pine stand at least 22 years old. However, they did observe that some damage will result from such fires when a single log burns against the butt of a tree or when fires persist in heavy resin exudation in bark crevices.

At Pechey State Forest heavy resin exudation in bark crevices on radiata and patula pines burns for periods up to five minutes. During 1977 and 1978 burning at Pechey, 267 ha of mainly patula pine plantations were burnt. A very low proportion of trees on the burnt area, 0.1 per cent, showed this property of resin burning. Eighteen months after the fire a sample of the worst affected trees were removed for a study of wood damage. Only one stem, 0.001 per cent of total, showed permanent wood damage, cambial death, blue stain fungus and a small amount of wood borer damage. The damage to this stem resulted from a single log burning against the butt of the tree for a very long period. Four other stems showed large amounts of traumatic resin in the outer layers resulting from the burning of exuded resin in bark crevices. No cambial death was evident in these stems eighteen months after the fire.

Kayll (1963), working with white pine (*Pinus strobus* L.) in Canada, compared outerbark temperatures with cambial temperatures for a range of bark thicknesses. He found that, with an average bark thickness of 0.4 in (10 mm), 500° C outer bark temperatures for five minutes did not raise the cambial temperature to 60°C, the normally accepted lethal temperature for living tissue. Van Loon (1973) found that, in a slash pine stand, with fire intensities less than 260 kw/m, 23 per cent of trees experienced a maximum temperature of 500°C during the fire. However, the persistence of temperatures greater than 100°C on these stems ranged from 167 to 188 seconds. Therefore, if the bark insulating properties of slash pine and white pine are similar, no cambial death should occur with fires less than 260 kw/m in intensity and bark thicknesses greater than 10 mm. Measured bark thickness in 17 years old slash pine plantation at Toolara ranged from 12.5 mm to 25 mm and averaged 18.5 mm. Prescribed burning techniques in slash pine plantations aim for fire intensities of less than 250 kw/m.

Soil Properties

Wells *et al.* (1979) conducted an intensive review of the literature on fire intensity and soil effects and concluded that fire intensity and the resultant degree of exposure of mineral soil to heat governed the degree of response of soil properties to fire. They found that productivity and stability of soils are both adversely affected by excessive heat, but that soil temperatures are not greatly increased by low intensity fire.

Wells *et al.* (1979) concluded further that low intensity fires facilitate the cycling of some nutrients, may help control of some plant pathogens and generally do not increase soil erosion. Intense fires volatilize excessive amounts of nitrogen and other nutrients, destroy organic matter, disrupt soil structure and may induce water repellancy, thus increasing soil erosion and decreasing productivity potential.

Appendix 1 lists fuel reduction data for a number of prescribed burns at Toolara State Forest. In most of these fires the quantity of fuel remaining was less than that described by Gilmour (1965) as being the minimum necessary for soil protection. Gilmour prescribed 7 tonnes per hectare as the minimum amount of litter to be left on the forest floor in hilly topography in the Australian Capital Territory. This figure is likely to be less on the predominantly flat terrain of the Queensland coastal lowlands.

No measurements of heating of soil or of soil loss have been done in prescribed burning operations in Queensland. However, the weight of evidence presented by Wells *et al.* indicates that little change can be expected in soil properties as a result of low intensity fire.

Nutrient Status of the Forest

Measurements of nutrient levels in the soil, litter layer and foliage have been carried out in association with prescribed fires at three yearly intervals since 1972 in an experimental area at Tuan State Forest.

No trends can be established in the data which have been collected at this stage.

Fuel Properties

Fine fuel quantity

Reduction of overall fine fuel quantity (material less than one cm diameter) by prescribed burning is directly related to the intensity of the prescribed fire which, in turn, is related to the characteristics of the fine fuel layer (fuel quantity, fuel depth, fuel suspension), fine fuel moisture content and meteorological conditions. Therefore, the range of fire intensities which have been used in prescribed burning operations in Queensland plantations have caused a range of fuel reduction rates.

Fuel quantity sampling before and after prescribed burns has been carried out over a range of plantation and fuel types under varying meteorological conditions. Fine fuel quantity is sampled by collecting and drying to constant weight all fine fuel down to mineral soil within a 0.25 m² square. The sampling square is located using the method of 'ranked sets' devised by McIntyre (1952).

The variation in fuel reduction expressed as a percentage of pre-fire fuel weight, is indicated in Appendix 1. The average fuel reduction over the range of fuel and meteorological conditions sampled was 56 per cent, less than the arbitrary maximum of 70 per cent for an ideal prescribed burn. The measured fuel reduction ranges from 9 per cent to 88 per cent with about 20 per cent of burns being above this arbitrary maximum.

Annual litter fall in plantations, more than about 13 years old, is in the range of 4 to 5.5 tonnes per hectare. Fine fuel quantities in plantations after canopy closure usually average between 10 and 24 t/ha when left unburnt. Without fire, litter input through litter

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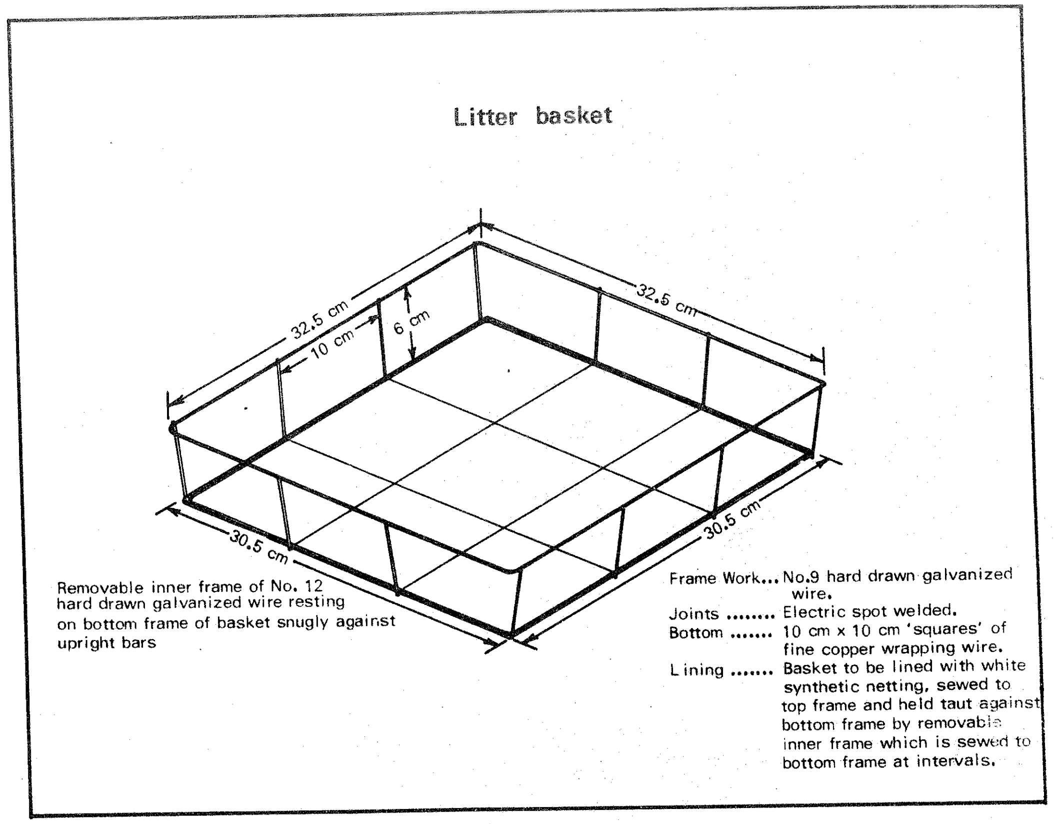
Figure 12. Litter basket



Removable inner frame of No. 12 hard drawn galvanized wire resting on bottom frame of basket snugly against upright bars

Frame Work... No.9 hard drawn galvanized wire.
Joints .... Electric spot welded.
Bottom .... 10 cm x 10 cm 'squares' of fine copper wrapping wire.
Lining .... Basket to be lined with white synthetic netting, sewed to top frame and held taut against bottom frame by removable inner frame which is sewed to bottom frame at intervals.

Details of the four sites measured are:

- Cardwell State Forest. Honduras Caribbean pine planted 1966/67.
- Bowenia State Forest. Honduras Caribbean pine mixed with some other species in an arboretum planted 1966/67.
- Elliot River State Forest. Honduras Caribbean pine planted 1965/66.
- Beerwah State Forest. Slash pine planted 1965.

Linear regression equations were developed to predict fine fuel moisture content at the four plantation sites. Further development of these equations or the development of non-linear equations is to be attempted to avoid some anomalies occurring in the predictions.

Drying models

The rate at which fine fuels dry away from the influence of edge exposure and after certain amounts of rain governs the fine fuel moisture content at any time and, consequently influences fire behaviour.

The first attempt to model the rate of drying in Queensland plantations was made in 1972 when a drying table of the form shown in the prescribed burning guide (Appendix 2) was constructed for Toolara State Forest. This table was subsequently expanded into two tables, one for exposed areas and poor site index or failed areas the other for areas inside plantations. Because of the variability of fuel drying experienced on exposed areas, it was decided to abandon the table for exposed areas and treat each exposed area as part of the surrounding plantation.

In 1975, a further refinement to the drying tables was considered necessary because areas which experienced higher mean daily temperatures during the burning season were experiencing quicker drying of fuels. Separate tables were then drawn up for mean daily maximum temperatures of between 20 and 30°C. Mean daily maximum temperatures for three regions for the March to August period were then drawn up to give a guide to the expected drying conditions in each month.

These tables were constructed in a format used in other States at that time and were adapted to fit experience gained from year to year.

In 1977, a drying study was initiated to test drying conditions empirically at four plantation centres, namely Beerwah, Elliot River, Bowenia and Cardwell.

The method used in this experiment was based on a technique reported by Wright (1967). Drying, or moisture loss, of fine fuels is measured by the decrease in weight of a standard litter basket (Figure 12) resting in natural position within the fuel layer on the forest floor. A section of litter the same size as the bottom of the tray is cut out and deposited intact in the tray. Trays are paired, one containing the full litter layer, the other the top of the litter layer to a depth of one to two centimetres.

Compact fuel beds away from exposed edges and in full shade were sampled. Six sites at each of the centres were selected.

The sample trays were removed from the litter layer and weighed at 1500 hours each day. The weighings coincided with measurement of temperature and relative humidity at the nearby recording station. A rain gauge, sited close to the measurement site was used to record rainfall at 0900 hours daily. Measurements continued until no further moisture loss was occurring. Trays were re-sited after three months of measurement to avoid substantial loss from decomposition.

Samples were then oven dried so that all moisture contents could be expressed as percentages of oven-dry weights. In this way, daily moisture contents of the full litter layer and the top of the litter layer at 1500 hours, and daily moisture losses were obtained to correlate with rainfall to 0900 hours, number of days since rainfall, maximum temperature, and minimum relative humidity. Multiple regression analyses were then carried out to examine, firstly, the effect of rainfall on moisture content and, secondly, the effect of temperature and relative humidity on moisture content in the absence of rain.

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fall reaches a state of equilibrium with litter decomposition, thus causing the fine fuel quantity to remain approximately unchanged on any particular area.

Some evidence is available to suggest that fine fuel quantities do not fully recover their pre-burn levels in three years in some areas (Table 10). However, for practical purposes, it can be assumed that fuel quantities over most plantation areas almost fully recover pre-fire levels three years after a low intensity fire.

Table 10. Fuel reduction and post-fire fuel accumulation from five prescribed burning experiments in slash pine plantations

A. Experiment 32 Fire

Before burning	Fine fuel quantity (t/ha)			
	After burning			
	Immediately	6 months	18 months	60 months
18.1	9.4	9.3	8.0	11.6

B. Experiment 33 Fire

Before burning	Fine fuel quantity (t/ha)			
	After burning			
	Immediately	6 months	18 months	60 months
15.6	3.6	3.5	6.3	9.1

C. Experiment 34 Fire

Before burning	Fine fuel quantity (t/ha)	
	After burning	
	Immediately	18 months
18.3	8.0	7.8

D. Experiment 36 Fire

Fine fuel quantity (t/ha)									
1972 Fire				1975 Fire			1978 Fire		
Unburnt	Before fire	After fire	12 months after	Unburnt	Before fire	After fire	Unburnt	Before fire	After fire
9.9	9.4	3.8	6.6	14.0	13.1	6.0	12.2	10.2	4.1
	Significance of difference between means - burnt and unburnt								
	N.S.				N.S.			N.S.	

E. Experiment 3 Fire

Fine fuel quantity (t/ha)					
1967 Fire		1972 Fire		1975 Fire	
Before	After	Before	After	Before	After
19.4	7.4	14.1	9.0	13.9	5.8

Fine fuel suspension

Fuel suspension depth can be defined as the vertical distance to which fine fuel particles, available to low intensity fires, are suspended above the litter layer in contact with the ground. The depth of suspension and the proportion of the area on which any suspension occurs are two variables which have been used to classify fuel types, so important are they considered to be in determining fire behaviour in plantation fuels.

Burning of plantation fuels decreases the amount of suspension by removing at least part of the understorey causing the suspension (Table 11). The reduction in suspension depends on the intensity of the fire and the extent to which the understorey species are removed. Generally, the area carrying suspended fuels approaches zero after a successful prescribed fire.

Table 11. Suspension of fine fuel before and after fires in a slash pine plantation

Per cent of area with fuel suspended to depths of:	Burnt plots			Unburnt plots			
	Pre-fire 1972	Post-fire 1972	1973	Pre-fire 1978	1972	1975	1978
Greater than 15 cm	13	0	0	9	4	7	8
8 to 15 cm	22	0	0	17	21	14	6
2 to 8 cm	45	0	0	15	44	35	7
Less than 2 cm	20	100	100	59	31	44	79

Recovery of suspension depends on the potential of the understorey species to recover the pre-fire density and height. There is usually little or no suspension in the first twelve months after a fire. Suspension then slowly increases but does not reach pre-fire levels within three years.

Other fuel types recover suspension levels depending on the rate of recovery of the understorey species causing suspension.

Understorey Composition

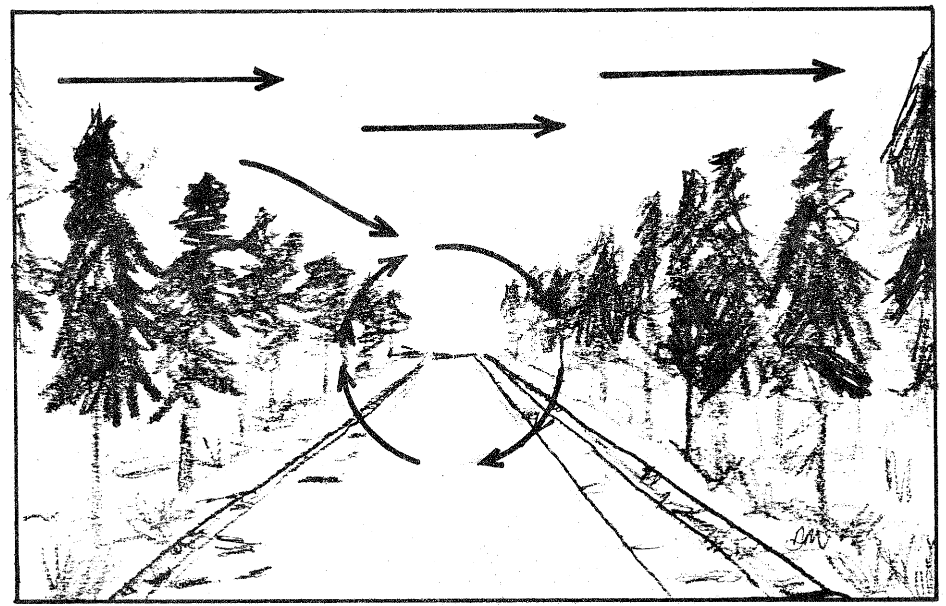
A system of point quadrats devised by Parker and Harris (1959) are used to indicate changes in understorey composition and frequency at periodic intervals. The point quadrats are 2 cm diameter loops located at fifty randomly selected points along a line. At each of these points, the decision is made whether the loop is occupied below the 1 metre level and by what species. The number of quadrats occupied are summed by species, this sum being termed the loop index which is an expression of frequency of species occurrence.

Fuel moisture content of both the full litter layer and the top centimetre of the litter layer increases rapidly from the plantation edge to about 10 m from the edge. Moisture content then remains approximately constant with increasing distance from the edge.

Roberts (1968) lists other effects of a small opening in a plantation which might be translated to plantation edges. Surface temperatures were about 40° F (22.2° C) higher in the opening than in the plantation. Vertical air movements were much greater in the opening than in the plantation. Both of these factors combined to give much greater convective activity in the open and could explain the tendency for fire to flare when reaching an opening or a plantation edge.

Other peculiar wind effects are known to occur on plantation edges. Edges adjacent to 30 m or 60 m wide firebreaks or any strips of cleared land experience these effects. These strips of cleared land have the effect of altering the predominant wind direction. On leeward edges the air movement tends to 'tumble' into these gaps causing wind eddies which effect a 180 degree shift in wind direction (Figure 11). Strips of cleared land also tend to produce a funnelling effect causing winds to change direction slightly along the cleared strip.

Figure 11. Wind eddies caused by forest openings



The magnitude of these effects depends on a number of factors such as the relative orientation of the edge to the prevailing wind direction, the height of vegetation on the opposite side of the opening from the plantation edge and the width of the opening.

DRYING OF FUELS

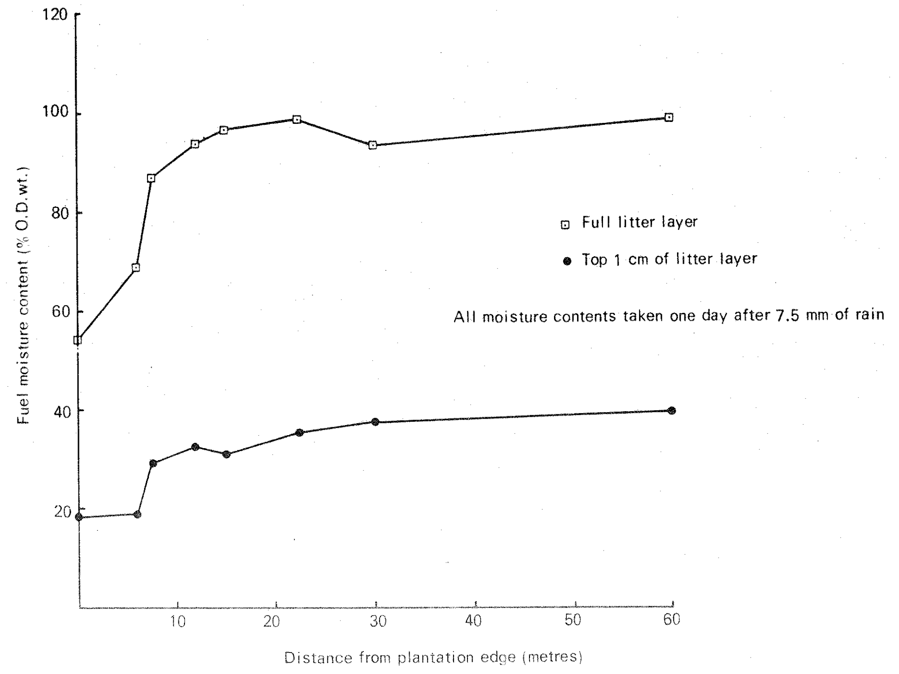
Edge exposure

Plantation edges, particularly northern and western edges, are known to burn with higher intensity than adjoining areas within a plantation. The reasons for this are:

- edges are more subject to the influences of sun and wind than the rest of the compartment, leading to more rapid drying of fuels.
- the increased amount of sunlight reaching the fuel layers on edges stimulates the growth of some understorey species such as blady grass and bracken fern. This change in the fuel structure causes fires to flare on edges.
- fire behaviour at the edges is influenced by wind. In plantations with a dense canopy the ratio of wind speed outside the forest to that inside is approximately five to one. In this situation the wind speed on the plantation edge is five times that inside the forest, with wind speed decreasing rapidly with increasing distance from the plantation edge.

The increased drying of fuels on plantation edges and the degree of influence of this effect have been investigated over a number of sites in the one area on the same day. The mean moisture contents at distances from the northern edge of the plantation are shown in Figure 10.

Figure 10. Fine fuel moisture content variation with distance from plantation edge



Density was measured by counting all species occurring in permanent circular plots 2.5 m^2 in area located to give a 0.15 per cent sample of the area. Loop index lines are systematically located and 30 m in length, one line for each three species density plots.

Fires in plantations, whether of high or low intensity generally remove enough of the litter layer to expose a good seed bed for germination of seed. Annual plants may germinate prolifically on this seed bed during the first year after fire but then die out gradually as further litter accumulation suppresses the germination of further annuals (Tables 12, 13 and 14).

Table 12. Understorey species density* (all heights) in three compartments before and after fire at Toolara State Forest

Species	Species density (number/ha)	
	Pre-fire	12 months post-fire
Grass tree		
. greater than 0.3 m	1080	865
. 0.15 to 0.3 m	3675	3153
. less than 0.15 m	16310	22270
. Total	21065	26288
Macrozamia	495	617
Bracken fern	2040	2965
Blady grass	2967	2380
Other grasses (*Lepidosperma, Paspalum* spp.)	5777	44350
Woody species (*Hakea, Banksia, Xylomelum, Tristania, Eucalyptus, Casuarina* spp.)	1647	1513
Vines (*Glycine, Passiflora, Kennedya, Rubus* spp.)	1545	3490
Herbs and Annuals (*Erigeron, Pratia, Drosera, Sonchus, Hybanthus, Eustrephus* spp.)	0	11430
Slash pine	0	1500

* *'Density' of a species is the number of that species occuring per unit area, usually one hectare*

Other plants, particularly groundsel bush (*Baccharis halmifolia* L.) and slash pine, capitalise on the exposure of good seed beds to germinate and become established when there is a good supply of seed available in the litter layer.

Table 13. **Loop index* and dominance+ in the less than one metre stratum within the understorey of a slash pine plantation burnt in 1972, 1975 and 1978**

Species	Loop Index (Dominance in brackets)			
	Pre-fire 1 (1972)		Pre-fire 3 (1978)	
	Burnt plots	Unburnt plots	Burnt plots	Unburnt plots
Grass tree	5(6)	1(1)	1(1)	1(1)
Miscellaneous grasses	43(51)	41(55)	49(40)	24(22)
Cutty grass	11(13)	9(12)	0(0)	0(0)
Passiflora spp.	3(4)	7(9)	17(14)	63(58)
Bracken fern	1(1)	3(4)	1(1)	0(0)
Blady grass	3(4)	1(1)	45(37)	11(10)
Slash pine	0(0)	0(0)	3(2)	5(5)
Herbs and Annuals	1(1)	1(1)	3(2)	1(1)
Couch grass	14(17)	8(11)	0(0)	0(0)
Paspalum spp.	2(2)	3(4)	0(0)	0(0)
Vines	1(1)	1(1)	1(1)	0(0)
Liliaceae and Orchidaceae	0(0)	0(0)	2(2)	4(3)

* *'Loop index' of a species is the number of registers of that species per 100 point quadrats and, as such is a measure of frequency of that species*

\+ *'Dominance' or 'relative cover' of a species is expressed by the number of registers of that species per 100 point quadrats as a percentage of the total number of registers of all species per 100 point quadrats*

Grass trees (*Xanthorrhoea* spp.) tend to quickly regain dominance after a fire even though the number of taller individual plants (greater than 0.15 m) decreases. This decrease is probably due to the burning of the tops of some individuals thus moving some individuals into a lower size class. The total number of grass tree plants appears to increase in the 12 months post-fire period, this being due at least partly, to the increased ease in location of individuals after removal of some of the surrounding vegetation with fire.

Gill and Ingwersen (1976), working with *Xanthorrhoea australis* R. Br. found that the early seedling stage of this species is the only stage vulnerable to death by fire. The subterranean phase is almost completely resistant. When the apex emerges above the soil the plants are protected by moist, densely packed leaf bases. If the apex is killed epicormic shoots ensure survival. Stems are generally well protected by densely packed leaf bases.

The results presented here indicate the degree of fire resistance of the genus *Xanthorrhoea*, various species of which comprise a major component of the understorey in pine plantations in Queensland.

Fine fuel suspension

Grass trees comprise a major constituent of the understorey of exotic pine plantations. The effect of grass trees on the suspension of needle fuel has been examined.

The frequency of grass tree bushes and the size of individual bushes were seen to contribute to the amount of suspension of fuel. One full compartment was sampled by 40 circular plots, 2.5 m^2 in area, located systematically on a grid spacing of 60 by 40 m. Within these plots all grass tree bushes were counted. Plots were classified according to the site index of the surrounding plantation. Fuel quantity was sampled in association with every second plot.

Table 20 gives the results of this investigation. The poorer site index areas carry a greater frequency of grass tree bushes but the individual bushes on these poorer sites contribute a smaller amount of combustible fuel. On individual plots the proportion of total fuel contributed by the bushes ranged from 8 to 20 per cent and the number of bushes ranged from 2 500 to 42 500 bushes per hectare.

Table 20. Fuel quantity contributed by grass trees (*Xanthorrhoea* spp.) and the number of grass tree bushes per 2.5 m^2 plot by site index class in one compartment at Toolara State Forest

	Site index classes (m)			
	18	21	24	27
Quantity of grass tree (t/ha)	0.75	2.26	2.01	2.26
Mean number of grass tree bushes per plot	6	6	4	3

The poorer sites carried a larger total area with grass trees and a larger number of bushes, each bush being of smaller size. Suspension caused by the bushes was, therefore, greater on the poorer sites with the consequent quicker drying of fuels and higher fire intensities.

The trends of greater area of suspended fuel caused by grass trees in low site index areas are not necessarily maintained for other species causing suspension. As a general observation, however, low site index areas and areas of low stocking carry fuels containing higher amounts of grasses, such as blady grass, sedges and other species including grass trees, than do high site index areas. Low site index and low stocking areas also carry low needle fuel quantities. The overall result, on low site index areas, is generally a highly suspended fuel containing a low needle fuel quantity.

The higher amounts of fuel suspension plus the greater penetration of wind to the fuel layers render low site index and low stocking areas more flammable than high site index and normal stocking areas.

Figure 8. **Forest floor ~~needle~~ litter in relation to cumulative needle fall at Beerwah State Forest**
(ex M.J. Finch, unpublished data)

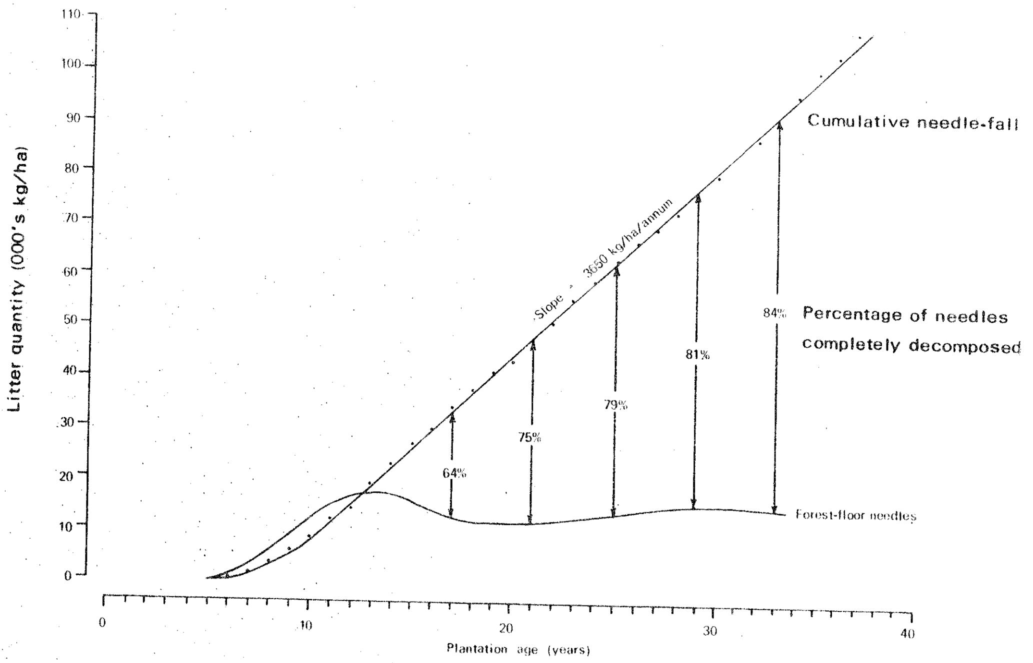
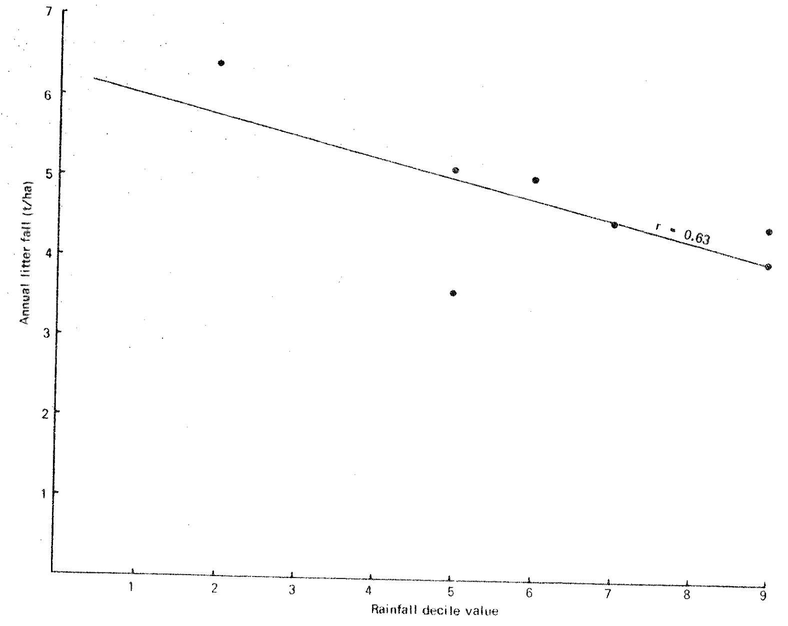


Figure 9. **Effect of drought on litter fall at one site on Toolara State Forest**



Bracken fern (*Pteridium aquilinum* (L.) Kuhn.) is an early coloniser after fire. Under favourable moisture conditions fronds of bracken fern appear on the burn site shortly after the fire. Bracken fern generally becomes suppressed as a result of competition for light: its importance value greatly decreased three years after a fire.

Macrozamia (*Macrozamia pauli-quilielmi* W. Hill F. Muell.) acts similarly to grass trees after fire, the increase in density being mainly due to location of extra individuals when the surrounding vegetation is removed.

Blady grass (*Imperata cylindrica* (L.) Beauv. var. *major* (Nees) C.E. Hubbard) gradually increases in dominance over a number of years but is then reduced in importance by competition for light from more shade tolerant species. Blady grass will retain dominance in areas where light conditions are favourable such as exposed plantation edges and areas of low site index or stocking.

Other grasses such as cutty grass (*Lepidosperma laterale* R. Br.) and couch grass (*Cynodon dactylon* (L.) Pers.) increase in density for at least 12 months after a fire, but then gradually become suppressed under competition for light.

Woody shrubs such as *Hakea plurinervia* F. Muell. ex Benth., *Hakea florulenta* Meissner, *Banksia oblongifolia* Cav., *Banksia integrifolia* L.f., *Xylomelum pyriforme* Knight, *Eucalyptus intermedia* R.T. Bak., *Tristania suaveolens* Smith, *Casuarina littoralis* Salisb., *Petrophila shirleyii* F.M. Bailey, *Lomatia silaifolia* (Smith) R. Br., and *Acacia aulacocarpa* Kunn. ex Benth. show a tendency to decrease in density and dominance after plantation fires. This decrease becomes more pronounced with repeated burning. The decrease in density and dominance of woody shrubs appears to be caused by fire in combination with a decrease in the vigour and health of shrubs as a result of competition under the canopy of a plantation. When growing outside a plantation these shrubs show high resistance to death by fire.

There appear to be differences in the reaction of woody species in the understorey to low intensity fires as compared to high intensity fires (Table 14). Scorch and some death in the plantation canopy after a high intensity fire improves light conditions thus stimulating the growth of woody species. Low intensity fires do not improve light conditions and inflict some damage on the stems from which they sometimes do not recover.

Table 14. **Species importance values* following one high intensity fire**

Species	**Importance Values**			
	6 months 1969	**14 months 1970**	**3 years 1972**	**5 years 1974**
Grass tree	39	41	41	31
Bracken fern	19	19	9	3
Blady grass	0	7	14	4
Other grasses	25	31	30	13
Woody species (*Eucalyptus, Acacia, Alphitonia* spp.)	0	4	8	1
Annuals	11	0	0	0
Groundsel bush	1	1	8	30

* *Importance value of a species is measured by the mean of the frequency and dominance figures for that species*

SMOKE CONTROL

Prescribed burning of exotic pine plantations carried out without crown scorch and without the complete removal of the soil protecting litter layer, leads to no obvious signs of environmental damage.

The major environmental constraint in prescribed burning of plantations is the minimising of smoke pollution, particularly in the region of populated areas, highways and airports. Winds should be used to carry smoke away from these smoke-sensitive areas. Burning when atmospheric conditions are slightly unstable avoids the problem of trapping smoke near the ground.

DEVELOPMENT OF PRESCRIBED BURNING TECHNIQUES

After about fifty years of complete fire exclusion from exotic pine plantations in Queensland the initial trials of prescribed burning techniques were begun with some trepidation at Toolara State Forest in 1967. Technique trials were continued at Toolara until 1973 when the techniques to be used in this area were able to be defined.

In 1974 these defined techniques were used in a large scale burning operation at Toolara and were extended to Tuan and Bowenia State Forests. Further extension of the burning techniques into plantations at Beerwah and Cathu was done in 1975. By 1976 the established techniques were being used in burning operations in all exotic pine plantation centres on the coastal lowlands.

In 1977 the burning techniques were further adapted to fit the different species composition and the different weather conditions in the plantations on the highlands at Pechey and Passchendaele State Forests.

From these extensive trials a number of conclusions were drawn on the techniques to be used.

TIMING

The weather conditions occuring in Queensland exotic pine plantation areas during the period March to June are suitable for prescribed burning. Some variation in the timing of burns is necessary between southern and northern Queensland plantations because of the earlier drought and the higher temperatures in north Queensland.

Variations in timing of burns within the March to June period in a particular area is often made necessary by the variations in rainfall and other weather conditions in that area.

Late morning, after the effects of overnight dew have decreased, till early afternoon, before day temperatures have decreased is the period during which most burning should be done. In some circumstances advantage can be taken of the higher fuel moisture contents occurring outside of this time.

FUEL PROPERTIES

Fine fuel quantity

The total quantity of litter fuel occurring on a site together with the dryness of this fuel constitutes the amount of fuel available for burning under a given set of conditions, known as the available fuel quantity.

The fine fuel layer of exotic pine plantations is made up of pine needles, understorey species which cause suspension of the pine needles and other material such as bark pieces, flowers, seeds, cones and twigs less than one cm in diameter. The understorey species will be considered in another section on fuel suspension. In this section, attention will be focussed on the pine needle and other material section of the litter layer.

Needle fall in slash pine in south-east Queensland follows a pattern of maximum quantity in late autumn (May), a minimum in mid-winter (July) and a steady increase through summer and autumn. Minor peaks may occur during the summer storm season as a result of high winds.

Storms and high winds have a major effect on the fall of other material. Slash pine seed fall is at a peak in April with 90 per cent falling from March to May. Slash pine flower fall peaks in August with 92 per cent falling in August and September (M.J. Finch, unpublished data).

Total annual litter fall in plantations older than 10 to 13 years lies in the range of 4 to 5.5 t/ha, about 90 per cent of which is needle fall. In younger plantations, litter fall decreases markedly. This factor is probably related to time of canopy closure and, therefore, varies with site index and original spacing.

At plantation ages of above about 13 years the quantity of needle litter remaining on the forest floor not decomposed remains relatively constant in the range 10 to 20 t/ha (Figure 8).

On one site at Toolara State Forest it has been shown that the annual total litter fall is related to the drought stress occuring during the year (Figure 9), increasing as rainfall decreases. This does not suppose that drought stress is the only factor which influences litter fall. Others such as the numbers of storms and periods of high wind and the presence of leaf-cast fungi are important but are difficult to quantify.

Fine fuel quantities in plantations of burnable age generally fall in the range 10 to 20 t/ha. Extreme fuel quantities do fall outside this range. The highest fuel quantity measured in Queensland plantations was 42.5 t/ha in a compacted slash pine fuel at Pechey State Forest, where decomposition rates are low because of low temperatures and low rainfall. Some young low site index areas carry fuels less than 10 t/ha.

Estimation of fine fuel quantity by measuring the depth of compacted fuel layers has been used in other states of Australia, particularly Western Australia. The relationship between fuel depth and fuel quantity has been investigated in Queensland but no significant correlation has been established. The fuel depth gauge used in Queensland has given readings which vary by up to 100 per cent between observers. More work is needed on the design of the gauge until comparability between observers can be established.

Site index tables were then used to determine the predominant height of stands for various ages and site indices (Table 17). The height to green crown corresponding with these predominant heights are listed in Table 18 by age and site index classes.

Table 17. **Predominant height (m) / site index / age relationships in slash pine plantations**
(Qld. Dep. For., unpublished data)

Site index (m)	Age (years)					
	10	12	14	16	18	20
18	9.9	11.3	12.8	14.0	15.1	16.1
21	11.2	12.9	14.6	16.0	17.3	18.6
24	12.6	14.5	16.4	18.1	19.5	21.0

The flame height - scorch height relationship (Table 15) was then used to give the prescribed flame heights for various age and site index classes (Table 19). To cater for changes in mean daily maximum temperatures, changes in tree spacings, differences between individual tree heights and average tree heights and increases in flame heights on junction zones, a margin of two to three metres between scorch height and green crown height was allowed.

Table 18. **The influence of age and site index on height to green crown (m) in plantations of slash pine (average stockings)**

Site index (m)	Age (years)					
	10	12	14	16	18	20
18	5.5	6.2	6.8	7.3	7.7	8.0
21	6.2	6.8	7.6	8.0	8.5	8.7
24	6.7	7.5	8.2	8.6	9.0	9.4

Table 19. **Maximum recommended flame heights (m)**

Site index (m)	Age (years)					
	10	12	14	16	18	20
18	0.5	0.7	0.8	0.9	1.1	1.2
21	0.6	0.8	1.0	1.1	1.2	1.4
24	0.8	1.0	1.1	1.2	1.4	1.5

WEATHER CONDITIONS

Generally the weather conditions occurring between March and June are suitable for burning Queensland exotic pine plantations.

The appropriate fine fuel moisture conditions are obtained during this period when the Drought Index[2] is less than 200 and at least 7 mm of rain has fallen recently on the site. The cumulative effect of a series of wet periods on fine fuel moisture content is best measured directly.

Ideally, daily maximum temperature should be 25° C or less; minimum relative humidity should be in the range 45 to 70 per cent; wind speed should be less than 20 km/hr and constant; wind direction should be constant and atmospheric conditions should be slightly unstable. These are ideal conditions which may be departed from with care.

FUEL CONDITIONS

Fine fuel should have been saturated and be drying from the top down before burning is contemplated. The fine fuel layer should be dry on top and wet underneath almos to the point of containing free water.

Differentiation between fine fuel layers can be made on the basis of the amount of suspension caused by understorey species. Increases in the amount of suspension can often be correlated with the age of the plantation, the site quality of the plantatio and the location of the fuel with respect to plantation edges. A more grassy and, hence, more flammable fuel usually occurs in young plantations; on plantation edges, particularly northern and western edges; and in low site quality or failed plantation areas.

Fine fuel quantity is less important than the area carrying suspended fuel in determining the flammability of a particular fuel layer.

Fine fuel types and, hence, the behaviour of fires in these fuels can change dramatically within small areas. An intimate knowledge of the fuel types is, therefore, essential so that lighting patterns can be planned in advance of burning.

The understorey species causing suspension and the density of those species have a marked effect on the fire behaviour of the fuel.

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[2] *'Drought Index' is a measure of moisture deficiency expressed in terms of points of rain necessary to bring deep litter and upper soil layers to saturation (Keetch and Byram 1968)*

STAND CHARACTERISTICS

Slash and Caribbean pine stands of average site index[3] can be burnt when they reach an age of between 10 and 12 years. Some refinement of techniques is needed to burn younger plantations, plantations carrying difficult fuel types and plantations of patula and radiata pines.

Definition of flame height or fire intensity limits for stands at varying stages of development was seen as necessary. Definition of stand development in terms of site index and age would be possible.

LIGHTING TECHNIQUES

Ignition using a series of single spot fires placed at intervals within the plantation on a square grid pattern, known as 'grid ignition', was considered to be the most suitable lighting technique for most fuels. The intervals should be calculated to allow for fires joining about two hours after igniton. Therefore, the grid interval should be twice the estimated rate of forward spread of the head fire. Forward rates of fire spread up to 50 m/hr, flame heights up to 1 m and fire intensities up to 250 kw/m are generally acceptable for most grid ignition situations.

Strip head fire technique can be used to burn compacted or damp fuel layers but it is open to error caused by faults of judgement. Grid ignition is a much safer technique.

Strip back fire technique was found to be a safe means of burning exposed plantation edges on the leeward side of a compartment and in heavy fuels, poor site quality areas and young stands when constant winds are experienced. However, back fires cannot be expected to spread more than 200 m in a day thus restricting the technique to narrow strips of plantation or in areas where firebreaks have been established at appropriate intervals perpendicular to the wind direction. Generally this technique is useful where wind and fuel influences make head fires too active.

Burning techniques can be flexible enough to cater for the changes in conditions encountered in any particular area. However techniques to be used should be planned before lighting an area. Members of a lighting team should not be allowed to make their own changes once the lighting has commenced.

DEVELOPMENT OF A BURNING GUIDE

FLAME HEIGHTS

One of the most directly measurable parameters of fire behaviour is flame height and the relationship between this and factors such as crown scorch can be determined. It is useful, therefore, to prescribe fire on the basis of the maximum flame height allowable.

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[3] *'Site index' is defined as the predominant height in metres of the stand at age 25 years from year of planting. Predominant height is calculated as the mean height of the tallest 50 stems/ha, usually determined from the tallest stem on each 0.02 ha.*

To obtain burns free of scorch the fire must be of such intensity and the flames of such a height as to cause a scorch height which is less than the green crown height. From McArthur (1962) a table (Table 15) of flame heights and corresponding scorch heights was developed. These scorch heights can be considered to be approximate only because Byram (1958) recorded that two fires of equal intensity would cause scorch heights of 8.5 ft (2.6 m) and 14.1 ft (4.3 m) on days with mean maximum temperatures of 60° F (15.6° C) and 82° F (27.8° C) respectively. To account for this and other factors the prescribed flame heights are adjusted to give scorch heights which are two to three metres less than the calculated green crown height.

Table 15. Flame height - scorch height relationships - (based on McArthur (1962))

Flame height (m)	Scorch height (m)	Flame height (m)	Scorch height (m)	Flame height (m)	Scorch height (m)
0.5	3.0	0.9	4.0	1.3	6.4
0.6	3.5	1.0	5.3	1.4	6.8
0.7	4.0	1.1	5.6		
0.8	4.5	1.2	6.0	1.5	7.2

Green crown height shows no correlation to average stand height over a range of stockings. Stocking affects the green crown height to a great degree within a particular average height class. Within an average stocking class the green crown height does increase as total height increases (T. Anderson, unpublished data).

For the range of predominant heights within which prescribed flame heights are likely to cause scorch, that is, 10 to 20 m, a green crown height can be assigned to a predominant height class for an average spacing (Table 16). These figures would decrease for higher spacings and increase for lower spacings.

Table 16. Height to green crown at average spacing in slash pine plantations
(Qld. Dep. For., unpublished data)

Predominant height (m)	Height to green crown	
	(m)	% of predominant height
10	5.6	56
12	6.5	54
14	7.3	52
16	8.0	50
18	8.6	48
20	9.2	46