Early plantation growth and tolerance to ramularia shoot blight of provenances of three spotted gum taxa on a range of sites in Queensland

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Summary

Early height growth and field tolerance to *Quambalaria pitereka*, the casual agent of ramularia shoot blight, were assessed for eleven provenances of *Corymbia citriodora* ssp. *variegata*, nine provenances of *C. citriodora* ssp. *citriodora* and eight provenances of *C. henryi*, within existing trials involving 22 diverse sites in Queensland. Not all taxa and provenances were present at all sites. The age at assessment varied, but was primarily between 10 and 21 mo. Assessments indicated that ramularia shoot blight at a specific site was closely associated with local climatic conditions, with mean annual rainfall being a useful indicator of the potential disease risk. It also appears that the mean annual rainfall at the origin of the provenance is a good indicator of the potential tolerance of the provenance to ramularia shoot blight, with the most tolerant provenances of all three spotted gum taxa originating from sites with more than 1000 mm.

Of the taxa and provenances tested, the Woondum provenance of *C. citriodora* ssp. *variegata* has consistently demonstrated good growth rates and high tolerance to ramularia shoot blight across a wide range of sites. It is recommended that this provenance or other similarly tolerant provenances be selected for use in all future *C. citriodora* ssp. *variegata* plantations in southern Queensland where annual rainfall exceeds 800 mm. For *C. citriodora* ssp. *citriodora*, the Herberton and Kirrama provenances demonstrated good growth rates and high tolerance to ramularia shoot blight across a range of sites. For *C. henryi* there was little difference between provenances in growth or tolerance to ramularia shoot blight. While general tolerance was low, some good individuals were observed in the Gold Coast and Myrtle Creek provenances.

The results presented in this paper provide guidance towards provenance selection for plantation establishment and on-going tree improvement for the three spotted gum taxa. It is anticipated that within a few years increasing quantities of seed from commercial seed orchards will become available, giving plantation growers a seed supply with considerably greater growth potential and tolerance of ramularia shoot blight than any source currently available from natural provenances.

Keywords: provenance trials; disease prevalence; tolerance; susceptibility; spotted gum; *Corymbia citriodora* ssp. *citriodora*; *Corymbia citriodora* ssp. *variegata*; *Corymbia henryi*; ramularia shoot blight; *Quambalaria pitereka*; Queensland

Introduction

The hardwood plantation industry is undergoing rapid expansion in southern Queensland and northern New South Wales, with the area planted each year increasing from about 2500 ha in 1995 to nearly 10 000 ha in 2000 (National Forest Inventory 2000). Most of these plantations have been established with the primary goal of producing high-value solid-wood products including sawlogs, poles and veneer (DPI–Forestry 1996; Bruskin 1999). As the timbers of the spotted gums have excellent properties, with high density, strength and durability, they are a major component of these plantations, with *Corymbia citriodora* ssp. *variegata* widely planted for sawlog production in these regions (Bruskin 1999; DPI–Forestry 2000). Two other spotted gums, *C. citriodora* ssp. *citriodora* and *C. henryi*, are also planted, but on a much smaller scale.

Corymbia citriodora ssp. *variegata* and *C. citriodora* ssp. *citriodora* are the most commonly harvested hardwoods in Queensland and are adapted to a wide range of environments throughout their natural range (DPI–Forestry 1998). Despite this, there were several failures in the spotted gum plantations established in the mid-1990s. This was primarily due to infection by the pathogen *Quambalaria pitereka* (Simpson 2000), previously known as *Ramularia pitereka* and *Sporothrix pitereka*, causing the disease commonly known as ramularia shoot blight (RSB). In native forests, *Q. pitereka* has been recorded on numerous *Corymbia* species including all the spotted gums, *C. tessellaris* and *C. intermedia* (Ivory 1998). These species are widely distributed throughout eastern Australia and would provide a natural source of inoculum for most sites planted in this region. RSB is characterised by the development of large, irregular, white shiny or powdery lesions, which cause leaf distortion and, in severe infections, death of leaves and dieback in young stems. In plantations established with susceptible provenances, repeated infection is common, with trees losing apical dominance, assuming a shrub-like habit and in some cases dying (Ivory 1998).

The early, widespread failures caused by RSB greatly reduced industry confidence in spotted gum as a plantation choice. In 1998, the planting of spotted gum was temporarily stopped by the Queensland DPI–Forestry and was greatly curtailed by State Forests of New South Wales. At the same time, however, early results from taxa evaluation trials and newly established *C. citriodora* ssp. *variegata* seed orchards indicated that there was significant

Table 1. Site details (including number of provenances of each taxon) for the 22 trials examined in this study. Sites are ordered by increasing site mean annual rainfall (MAR).

Site no.	Site identity	Site location	Latitude (S)	Longitude (E)	MAR (mm)	Altitude (m)	Soil type	No. of provenances		
								CCC	CCV	CH
1	Greenmount	30 km S of Toowoomba	27°50'	152°02'	690	480	Brown Clay	2	4	–
2	Langley Flats	36 km S of Monto	25°06'	151°13'	733	200	Black Earth	2	2	–
3	Abercorn	32 km S of Monto	25°05'	151°10'	733	230	Yellow Podzolic	2	2	–
4	Monto	5 km SW of Monto	24°54'	151°05'	733	235	Yellow Podzolic	–	2	–
5	Tellebang	25 km S of Monto	25°05'	151°02'	733	250	Krasnozem	2	4	2
6	Mulgildie	20 km S of Monto	24°59'	151°11'	733	285	Prairie Soil	4	4	2
7	Cania Gorge	18 km NW of Monto	24°47'	151°00'	770	330	Red Earth	3	4	2
8	Mundubbera	22 km SE of Mundubbera	25°41'	151°26'	770	300	Krasnozem	–	2	–
9	Memerambi	3 km E of Memerambi	26°26'	151°53'	780	500	Krasnozem	1	2	–
10	Ropely	14 km S of Gatton	27°40'	152°17'	788	210	Grey Clay	–	4	–
11	Coominya	5 km SW of Coominya	27°25'	152°25'	810	70	Solodized Solonetz	–	4	2
12	Sugarbag	40 km S of Mount Garnet	17°55'	144°59'	810	400	Yellow Earth	4	3	–
13	Yarraman	12 km N of Yarraman	26°49'	151°58'	900	500	Krasnozem	–	1	2
14	Blackbutt	8 km SE of Blackbutt	26°55'	152°08'	960	440	Krasnozem	–	3	–
15	Kilcoy	10 km E of Kilcoy	26°56'	152°40'	975	110	Grey Podzolic	2	2	–
16	Kolan River 1	45 km S of Miriam Vale	24°41'	151°41'	1050	80	Yellow Podzolic	–	2	–
17	Kolan River 2	45 km S of Miriam Vale	24°41'	151°41'	1050	80	Yellow Podzolic	2	4	2
18	Hillgrove	35 km S of Miriam Vale	24°35'	151°38'	1050	80	Yellow Podzolic	2	2	–
19	Tiaro	4 km W of Tiaro	25°43'	152°33'	1070	25	Grey Podzolic	–	2	–
20	Imbil	5 km W of Imbil	26°28'	152°37'	1186	90	Grey Podzolic	–	2	–
21	Veteran	20 km NE of Gympie	26°03'	152°44'	1200	150	Yellow Earth	–	2	–
22	Tuan	28 km SE of Maryborough	25°47'	152°50'	1323	50	Red Podzolic	–	–	5

variation between provenances in tolerance to RSB (Lee *et al*. 1998). Provenances originating from high-rainfall coastal areas were more tolerant of RSB than provenances from drier inland areas. Amongst those tested, the Woondum provenance (rainfall 1250 mm) exhibited the greatest tolerance to RSB (Nikles *et al*. 2000). This discovery resulted in the DPI–Forestry re-introducing *C. citriodora* ssp. *variegata* to its plantation program in 1999, using seed mainly of the Woondum provenance.

To confirm these early results and to further examine variation in tolerance of RSB between spotted gum species, subspecies and provenances, the Queensland Department of Primary Industries established a large series of trials across a wide range of site and soil types in Queensland. These trials include a broad range of provenances of the three locally-occurring spotted gum taxa. This paper presents and discusses data on early growth and tolerance to RSB from the trials, and gives preliminary recommendations for taxa and provenance selection in Queensland.

Taxonomy of spotted gums

The spotted gums of eastern Australia have recently undergone a number of taxonomic revisions, resulting in the recognition of four distinct taxa (McDonald and Bean 2000). *Corymbia citriodora* ssp. *citriodora* (CCC or lemon-scented gum) extends from the Atherton Tablelands and Hughenden in northern Queensland, southwards to Springsure and Maryborough. *Corymbia citriodora* ssp. *variegata* (CCV or spotted gum) overlaps CCC in its northern distribution between Monto and Maryborough and extends westwards to Carnarvon Gorge and southwards to the upper Nymboida River and Coffs Harbour district in northern New South Wales. *Corymbia henryi* (CH or large-leaved spotted gum) has a limited distribution and occurs in the coastal strip from Esk in south-eastern Queensland to near Grafton in northern New South Wales. *Corymbia maculata* (CM or southern spotted gum) overlaps with the southern distribution of CCV in northern New South Wales and extends southwards to Orbost in eastern Victoria (Hill and Johnson 1995). This paper discusses only the three taxa that occur naturally in Queensland.

Methods

Study sites

Over recent years, the Queensland Department of Primary Industries has established a large number of taxa x site evaluation trials and provenance seedling seed orchards throughout Queensland for the three spotted gum taxa occurring in that state. Of these trials, 22 were sampled in this study. The trial sites represent a broad range of climatic and soil types, most of which have high potential for the establishment of spotted gum plantations. Each trial contains a minimum of two spotted gum taxa. The 22 sites cover a wide geographical range from near Mount Garnet (17°55'S, 144°59'E) in the north, to near Toowoomba

Table 2. Details of provenance* for each spotted gum taxon (SF = State Forest). For each taxon, provenances are ordered by increasing mean annual rainfall (MAR) of the provenance origin.

Taxon	Provenance	Provenance details	No. of parents	Latitude (S)	Longitude (E)	MAR (mm)	Altitude (m)
CCV	South Africa	SAFCOL CSO, South Africa ex Australia	16	–	–	–	–
	Carnarvon	Presho SF, 75 km W of Theodore	50	25°13'	149°13'	634	520
	Warwick	Leyburn SF, 45 km NW of Warwick	6/20	28°03'	151°03'	650	500
	Jandowae	Dimondy SF, 30 km NE of Jandowae	20	26°35'	151°17'	690	400
	Monto	Coominglah S.F., 15 km W of Monto	9	25°00'	151°00'	750	400
	Gatton	Lockyer SF, 15 km N of Gatton	7	27°28'	152°17'	788	150
	Wondai	Cherbourg SF, 7 km SE of Wondai	12	26°22'	151°55'	800	350
	Brooyar	Brooyar SF, 17 km W of Gympie	12	26°10'	152°30'	1000	90
	Veteran	Gympie SF, 20 km NE of Gympie	17	26°05'	152°43'	1200	137
	Wolvi	Goomboorian SF, 18 km E of Gympie	4	26°07'	152°46'	1250	236
	Woondum	Cooran SF, 8 km N of Pomona	>12	26°15'	152°49'	1250	120
CCC	Hughenden	Cheviot Hills, 130 km N of Hughenden	20	19°38'	144°12'	673	920
	Biloela	Biloela township	15	24°24'	150°30'	703	173
	Glendon	55 km W of Eungella	10+	21°10'	147°53'	740	300
	Mount Garnet	35 km S of Mount Garnet	12	18°10'	145°11'	830	700
	Calliope	Calliope Range, 35 km SW of Calliope	10	24°12'	150°55'	850	150
	Gladstone	10 km W of Gladstone	8	23°50'	151°09'	1020	20
	Yeppoon	15 km SW of Yeppoon	10+	23°10'	150°40'	1100	50
	Herberton	Woodleigh SF, 15 km W of Atherton	300	17°29'	145°22'	1100	900
	Kirrama	Kirrama SF, 25 km NW of Kennedy	8	18°12'	145°46'	1500	560
CH	Gatton	Lockyer SF, 15 km N of Gatton	10	27°28'	152°17'	788	150
	Braemar	Braemar SF, 20 km S of Casino, NSW	10	29°03'	152°59'	1100	90
	Gibberagee	Gibberagee SF, 52 km N of Grafton, NSW	6	29°14'	153°10'	1100	50
	Devines	Devines SF, 8 km S of Grafton, NSW	18	29°47'	152°58'	1100	40
	NSW plus trees	Natural selects from Grafton district, NSW	3	–	–	1100	50–90
	Banyabba	Banyabba SF, 36 km N of Grafton, NSW	9	29°23'	152°85'	1100	60
	Myrtle Creek	Myrtle Creek SF, 30 km S of Casino, NSW	11	29°09'	152°59'	1100	50
	Gold Coast	Nerang SF, 5 km NW of Nerang	9	27°59'	153°19'	1200	100

*All provenances are of Queensland origin except where indicated

(27°50'S, 152°02'E) in the south, and sample a rainfall range of 690–1320 mm y^{-1}. Descriptions of the sites of the 22 trials, including location, latitude, longitude, altitude, mean annual rainfall (MAR) and soil type, are given in Table 1. As the incidence of RSB is recognised as increasing with greater site rainfall and humidity, the sites in this table have been ordered by increasing MAR. For most of the 22 sites, accurate figures for the amount of rainfall and number of rain days between tree planting and assessment of RSB were not available.

Provenance treatments

Within the 22 trials, a total of 28 provenances was assessed for height growth and RSB symptoms. The provenances examined represent the geographical range of each taxon and are those for which seed was readily available at the time each trial was established. The provenances investigated include 11 provenances of CCV, nine provenances of CCC and eight provenances of CH. The numbers of provenances per site are shown in Table 1. Provenance descriptions including location, altitude and rainfall are given in Table 2. As the MAR of the provenance origin may give an indication of historical long-term RSB exposure and potential RSB tolerance, the provenances of each taxon have also been ordered in this table by increasing MAR.

Experimental design

All trials had a randomised complete block design, although replication and plot size varied between them. The number of replications varied between 2 and 16, and plot layouts varied from line plots of 10 trees to large plots of 72 trees. The minimum number of trees measured for any one provenance at a particular site was never fewer than 40 and in most cases ranged from 60 to 100. A summary of each trial is presented in Table 3.

Experiment establishment and management

All trials were established by research personnel and involved 'best practice' silvicultural techniques identified for individual site types (Dickinson *et al*. 1998). Site preparation involved deep ripping followed by cultivation of the tree rows. Sites with heavy-textured soils or drainage problems were high-mounded using a Savanna 'Tomahawk' bedding plough. For each trial, trees were grown as containerised seedlings at the Toolara, Beerburrum or

Table 3. Experiment details and measurement dates for the 22 trial sites

Site no.	Site identity	Planting date	Plot size (rows x trees)	No. of replications	Trees measured / provenance
1	Greenmount	02/2000	3 x 7	4	84
2	Langley Flats	04/1999	3 x 7	3	63
3	Abercorn	04/1999	3 x 7	3	63
4	Monto	04/1999	3 x 7	4	84
5	Tellebang	04/1999	3 x 7	2	42
6	Mulgildie	04/1999	3 x 7	3	63
7	Cania Gorge	04/1999	3 x 7	3	63
8	Mundubbera	03/1998	3 x 7	16	336
9	Memerambi	04/2000	7 x 10	3	210
10	Ropely	03/1998	3 x 7	4	84
11	Coominya	03/1998	3 x 7	3	63
12	Sugarbag	02/2001	1 x 10	4	40
13	Yarraman	03/1998	7 x 4	2	56
14	Blackbutt	04/1998	2 x 7	3	42
15	Kilcoy	02/2000	6 x 12	3	216
16	Kolan River 1	03/2000	3 x 7	2	42
17	Kolan River 2	03/2000	3 x 7	2	42
18	Hillgrove	04/2000	6 x 10	3	180
19	Tiaro	02/1999	6 x 7	3	126
20	Imbil	01/1999	4 x 10	2	80
21	Veteran	01/1998	3 x 7	2	42
22	Tuan	04/1997	1 x 28	4	112

Walkamin DPI–Forestry nurseries. No fungicides to minimise RSB incidence within nursery stock were applied at any of these nurseries. Seedlings were conditioned and sun-hardened prior to dispatch from the nursery and were in an optimal condition, with few or no obvious RSB symptoms prior to planting. Planting was by hand using grubbers, spades or potoputkis. In many cases, trees were hand watered (2–3 L tree^{-1}) immediately after planting. Tree rows were kept free of weeds by herbicides to a width of 2.5 m for a minimum of 12 mo after planting. Fertiliser was applied to all trials and consisted of a minimum of 60 kg P ha^{-1} and 28 kg N ha^{-1} at planting, and a follow-up application of 60 kg N ha^{-1} at age 9–12 mo.

Measurement

For all sites (except site 22) tree height was measured by research staff at ages of 6–14 mo. A trained field crew assessed RSB symptoms at a tree age of 11–21 mo (except sites 13 and 22 that were assessed at ages of 43 and 54 mo respectively). It has been observed that if RSB is present in a region, widespread infection occurs within the first 9 mo after planting. Consequently in order to make an accurate and efficient assessment of RSB, measurement is most reliably performed at an age of 9–24 mo. RSB was assessed subjectively by eye, scoring individual trees on a scale of 1–5 (see below). This assessment identified both active infection and the highly characteristic symptoms of any past infection including tip dieback and stem distortion.

The scale used in assessing symptoms (both active and suspected) of RSB is:

1 = Nil: no current or previous evidence of infection

2 = Light: some leaf lesions and/or lateral stem dieback, but no impact on tree form

3 = Moderate: numerous leaf lesions and/or stem dieback visible; form may be improved by pruning

4 = Severe: many lesions and/or severe stem dieback, multi-stemming, form very poor

5 = Critical: total infection, shrub-like growth, close to death.

Data analysis

Mean height and mean RSB symptom data were statistically examined using a one-way analysis of variance (ANOVA) to detect any differences between provenances. Where *F*-values were statistically significant ($P < 0.05$), differences between the means were compared using the Least Significant Difference (LSD) test. Due to the importance of the Woondum provenance of CCV to the hardwood plantation industry and its inclusion in 19 of the 22 study sites, a further comparison was made of the fraction of Woondum individuals present in each of the five categories of RSB symptoms. In this exercise, the cumulative RSB scores for populations at each site were plotted against increasing site mean annual rainfall to produce a series of regression curves.

Results

Ramularia shoot blight in *Corymbia citriodora* ssp. *variegata*

Where CCV was planted on sites with <750 mm MAR (sites 1–6), the mean RSB score was low (≤1.4, Table 4), with a significant difference between provenances recorded only at site 6. At this site, both the Gatton and Jandowae provenances recorded significantly higher RSB scores than the Woondum and Monto provenances. At sites with MAR 750–800 mm (sites 7–10), the RSB scores were generally higher (1.2–2.8), with significant differences recorded for sites 7, 8 and 10. At site 7, the Jandowae provenance had a significantly higher RSB score than the Woondum, Gatton and Monto provenances. At site 8, the Monto provenance had a significantly higher RSB score than the Woondum provenance. At site 10, the Carnarvon provenance had a significantly higher RSB score than the Warwick, Monto and Woondum provenances.

For CCV on sites with >800 mm MAR (sites 11–22), RSB scores were moderate to severe (1.7–4.2, Table 4), with significant differences recorded between CCV provenances at all sites except sites 13 (only one CCV provenance present), 16, 18 and 21. At site 11, the RSB score for the Woondum provenance was significantly lower than for both the Carnarvon and Warwick provenances. At this site, the Monto provenance also had a significantly lower RSB score than did the Carnarvon provenance. On the one site in northern Queensland (site 12), the RSB score was significantly lower in the Monto and Brooyar provenances than in the Wondai provenance. At site 14, the RSB score for the Woondum provenance was again significantly lower than for both the Carnarvon and Monto provenances. At site 15, the RSB score was significantly lower for the Woondum provenance than for the Brooyar provenance. At site 17, the RSB score was significantly lower for the Woondum and Monto provenances than for the Warwick provenance. On this site, the derived South Africa provenance (possibly hybrids between CCV and CM) recorded the highest RSB score of any of the 28 spotted gum provenances tested in this study, and this score was significantly higher than that of the other three CCV provenances at this site. At sites 19 and 20, the Woondum provenance had a significantly lower RSB score than did the Warwick provenance.

Ramularia shoot blight in the Woondum provenance of *Corymbia citriodora* ssp. *variegata*

The regression curves of cumulative RSB score (Fig. 1) illustrate a clear trend of decreasing numbers of useful trees (scores 1 or 2) with increasing rainfall at the trial site. The fraction of trees with no visible symptoms of RSB (score = 1) is above 80% for sites ≤770 mm MAR (sites 1–8). With increasing trial site rainfall, however, there is a marked reduction in the fraction of uninfected trees. On Woondum provenance trees of CCV at sites with >800 mm MAR (sites 11–22), about 40% of trees had no symptoms of RSB. The fraction of trees with no or minimal RSB symptoms (scores 1 or 2) follows a similar trend, dropping quickly on sites ≥788 mm MAR and stabilising at a level of about 70%. The remaining 30% of the tree populations on these sites consist of trees with RSB scores of 3 or more. These trees are characterised by poor form and growth problems, and are unlikely to develop into satisfactory plantation trees.

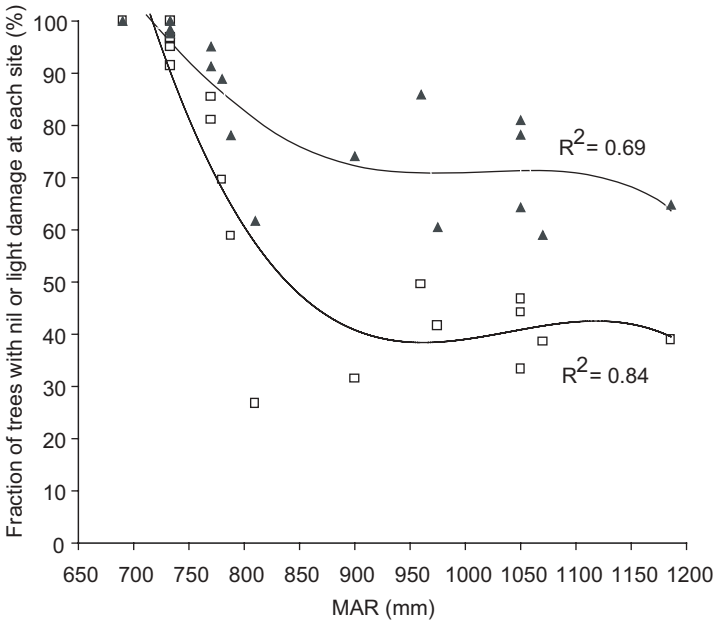

Figure 1. Fraction of Woondum provenance CCV trees with no damage (squares) or combined nil and light damage (triangles), plotted against the MAR of the 19 trial sites where this provenance is planted

Ramularia shoot blight in *Corymbia citriodora* ssp. *citriodora*

Where CCC was planted on sites with <800 mm MAR (sites 1, 2, 3, 5, 6, 7 and 9), RSB scores were generally low (≤1.9, Table 4), with significant differences between provenances at sites 6 and 7 only. Of the range of CCC provenances tested, the Kirrama provenance, which was represented on five of these seven sites, consistently recorded very low RSB scores. At site 6, RSB scores were significantly different between all provenances, with the Kirrama provenance the lowest, followed closely by the Hughenden provenance. The RSB score was higher in the Yeppoon provenance and greatest in the Calliope provenance. At site 7, the three provenances tested were all significantly different from each other, with the Kirrama provenance recording the lowest RSB score, Biloela an intermediate score and Calliope performing poorly with the highest score for RSB.

On the four sites with >800 mm MAR (sites 12, 15, 17 and 18), RSB scores were generally higher (1.2–3.2, Table 4), with significant differences between provenances. At site 12, the RSB score was significantly lower in the three northern Queensland provenances (Herberton, Mount Garnet and Hughenden) than the Glendon provenance. At sites 15 and 18, the Gladstone provenance recorded significantly lower RSB scores than the Yeppoon provenance. At site 17, the Herberton provenance recorded a significantly lower RSB score than the Biloela provenance.

Ramularia shoot blight in *Corymbia henryi*

For the CH provenances planted on sites with MAR <800 mm (sites 5, 6 and 7), RSB scores were low (≤1.5, Table 4). Differences between provenances were minimal, except on site 6 where the Myrtle Creek (NSW) provenance had a significantly lower RSB score than the Gatton provenance. At sites with >800 mm MAR (sites 11, 13, 17 and 22), RSB scores were higher (≥2.7, Table 4).

Table 4. Mean RSB scores assessed for individual spotted gum taxa and provenances at the 22 sites examined, grouped by MAR

Taxa	Provenance	<750 mm						750–800 mm				>800 mm											
	Sites:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
CCV	S. Africa	1.0																4.2					
	Carnarvon										2.8	3.1			2.8							3.4	
	Warwick	1.0									1.9	2.8						3.1		3.7	3.2		
	Jandowae					1.2	1.4	2.1															
	Monto	1.0	1.0	1.1	1.3	1.1	1.1	1.3	1.9		1.9	2.4	3.2		2.4			2.3					
	Gatton					1.1	1.4	1.3															
	Wondai												4.0										
	Brooyar									1.6			2.8			2.7			2.2				
	Veteran																2.2						
	Wolvi																					3.4	
	Woondum	1.0	1.1	1.1	1.1	1.0	1.0	1.2	1.3	1.5	1.7	2.2		2.1	1.7	2.2	2.1	1.9	1.8	2.2	2.2		
CCC	Hughenden						1.2						2.0										
	Biloela	1.0		1.3		1.2		1.5										2.6					
	Glendon												3.2										
	Mt Garnet												2.3										
	Calliope		1.0				1.9	1.8															
	Gladstone									1.5						2.6			2.2				
	Yeppoon						1.4									3.1			2.8				
	Herberton												2.2					1.2					
	Kirrama	1.0	1.1	1.0		1.0	1.0	1.0															
CH	Gatton					1.0	1.5	1.4										3.0					
	Braemar, NSW											3.9		3.5									
	Gibberagee, NSW																						4.0
	Devines, NSW																						3.9
	NSW, Grafton																						3.9
	Banyabba, NSW																						3.7
	Myrtle Ck, NSW						1.1					3.6		3.4									3.7
	Gold Coast					1.0		1.3										2.7					
LSD ($P < 0.05$)		–	–	–	–	–	0.2	0.3	0.1	–	0.4	0.6	0.4	0.2	0.7	0.5	–	0.5	0.5	0.6	0.6	–	–
Significance of F		–	ns	ns	ns	ns	***	***	*	ns	***	***	***	**	*	*	ns	***	**	*	*	ns	ns
Standard error		–	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.2	0.2	0.0	0.2	0.1	0.5	0.1	0.3	0.1	0.3	0.7	0.1

Significant differences between treatments are indicated as follows: ns = not significant, * = P <0.05, ** = P <0.01, *** = P <0.001.

At sites 11 and 13, the Myrtle Creek provenance recorded lower RSB scores than the Braemar provenance, but these differences were not significant. At site 17, the Gold Coast provenance recorded a lower (although not significantly so) score than the Gatton provenance. The highest RSB score for CH was at site 22, where rainfall was also the highest (1323 mm MAR). On this site RSB scores were between 3.7 and 4.0, and although there were no significant differences between provenances, the Myrtle Creek and Banyabba provenances recorded the lowest scores.

Tree height of all three taxa

At sites with <750 mm MAR (sites 1–6), variation in height growth between CCV provenances was relatively small (Table 5), except at site 5, where the Gatton provenance was significantly shorter than the Jandowae provenance. At sites with >750 mm MAR (where RSB was more severe), height growth was lowest in the CCV provenances with the highest RSB scores. At site 7, this included the Gatton provenance, which was significantly shorter than the Jandowae, Monto and Woondum provenances. At site 8, the Monto provenance was significantly shorter than the Woondum provenance. At sites 10 and 11, the Carnarvon provenance was significantly shorter than the Warwick, Monto and Woondum provenances. At site 14, the Carnarvon provenance was significantly shorter than the Monto and Woondum provenances. At site 17, the South Africa and Warwick provenances were significantly shorter than the Monto and Woondum provenances. The Warwick provenance was also significantly shorter than the Woondum provenance at sites 19 and 20.

Height growth of CCC (Table 5) was greatest in the provenances with the lowest RSB scores. In particular, the Kirrama and Herberton provenances from northern Queensland had good height growth on the sites where they were represented. The Kirrama provenance was significantly taller than the Biloela provenance at site 1 and both the Biloela and Calliope provenances at site 7.

Table 5. Mean heights (m) of individual spotted gum taxa and provenances, measured at ages 6 to 54 mo at the 22 sites examined

Taxa	Provenance	<750 mm MAR						750–800 mm MAR				>800 mm MAR											
	Sites:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
CCV	S. Africa	1.2																2.1					
	Carnarvon										1.9	1.6			1.8							2.1	
	Warwick	1.4									2.8	2.3						2.7		2.8	3.0		
	Jandowae					2.5	2.1	2.9															
	Monto	1.2	1.6	1.9	2.7	2.3	2.2	3.2	2.5		3.0	2.6	2.6		2.6			4.0					
	Gatton					1.8	2.1	2.6															
	Wondai												2.2										
	Brooyar									1.4			3.0			2.8			3.9				
	Veteran																2.8						
	Wolvi																					2.2	
	Woondum	1.3	1.6	1.8	2.8	2.2	2.1	3.2	3.0	1.3	3.1	2.7		1.0	3.5	2.9	2.4	3.9	3.7	3.9	3.8		
CCC	Hughenden						1.9						2.6										
	Biloela	1.3		1.7		2.2		2.8										2.9					
	Glendon												2.4										
	Mt. Garnet												3.4										
	Calliope		1.8				2.1	2.7															
	Gladstone									1.1						2.7			3.1				
	Yeppoon						1.7									2.6			2.9				
	Herberton												3.4					4.7					
	Kirrama	1.7	2.3	1.8		2.7	1.9	3.4															
CH	Gatton					2.3	1.9	3.5										3.3					
	Braemar, NSW											1.2		0.5									
	Gibberagee, NSW																						6.1
	Devines, NSW																						6.5
	NSW, Grafton																						6.3
	Banyabba, NSW																						6.8
	Myrtle Ck, NSW						1.1					1.4		0.5									7.0
	Gold Coast					2.2		3.7										3.4					
LSD ($P < 0.05$)		0.4	–	–	–	0.7	0.6	0.5	0.4	–	0.5	0.6	0.4	0.2	1.1	–	–	0.7	0.7	1.0	0.6	–	–
Significance of F		*	ns	ns	ns	*	*	**	*	ns	**	***	***	**	*	ns	ns	***	*	*	*	ns	ns
Standard error		0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.3	0.1	0.7	0.2	0.5	0.5	0.3	0.5	0.3

Significant differences between treatments are indicated as follows: ns = not significant, * = P <0.05, ** = P <0.01, *** = P <0.001.

At site 12, the Herberton and Mount Garnet provenances were significantly taller than the Hughenden and Glendon provenances. At site 17, the Herberton provenance was significantly taller than the Biloela provenance.

Across most sites there appears to be little difference in the height growth of the various CH provenances (Table 5). The only significant difference recorded was at site 6, where the Gatton provenance was significantly taller than the Myrtle Creek provenance. On the remaining sites where represented, the Myrtle Creek and Gold Coast provenances tended to exhibit the greatest height growth.

Discussion

Influence of site rainfall on ramularia shoot blight

For the range of CCV, CCC and CH provenances tested, RSB scores were low (<2.0) on sites where MAR was <750 mm (sites 1–6). As site MAR increased (750–800 mm MAR), RSB scores also increased, with sites 7–10 recording a moderate RSB score (<3.0) within susceptible provenances. On sites with >800 mm MAR (sites 11–22), RSB scores were higher, resulting in widespread, severe damage and some tree deaths within the most susceptible provenances.

Ramularia shoot blight in *Corymbia citriodora* ssp. *variegata*

At the 19 sites where the Woondum provenance of CCV was represented, no other CCV provenance recorded a significantly lower mean RSB score. Across all these sites, the highest recorded mean RSB score for the Woondum provenance was only 2.2 on sites 11, 15, 19 and 20. At sites with >800 mm MAR, where the RSB score was moderate to severe amongst other more susceptible provenances, about 40% of the Woondum provenance of CCV trees recorded no visible symptoms of RSB and a further 30% of trees displayed only minimal symptoms of infection. This large fraction of undamaged stems (70%) maintains plantation viability, given that DPI–Forestry hardwood sawlog-plantations are thinned pre-commercially to 40% of the initial tree stocking (1000 trees ha^{-1}) at age 1.5–3.5 y (Dickinson *et al.* 1998).

Of the remaining high-rainfall CCV provenances (>1000 mm MAR), both the Brooyar and Veteran provenances performed well on the limited number of sites where they were represented. The Wolvi provenance, however, performed very poorly on the one site where it was represented, with severe infection on most trees. It is important to note that this provenance seedlot was collected from only four parent trees and it is likely that this small sample does not truly represent RSB tolerance within the natural population of this provenance. This is indicated by recent results from other sites where superior RSB tolerance has been identified for the Wolvi provenance of CCV when a wide range of families was tested (I. Johnson[1], *pers. comm.* 2002). Other CCV provenances that have demonstrated moderate to high RSB tolerance on other sites include collections from higher-rainfall NSW regions such as Richmond Range State Forest (1100 mm MAR) and Wedding Bells State Forest (1600 mm MAR) (I. Johnson, *pers. comm.* 2002).

Of the lower-rainfall CCV provenances (<1000 mm MAR), the Monto provenance consistently recorded the lowest level of infection. In particular, at site 17 (1050 mm MAR) where RSB scores were high (up to 4.2), this provenance performed well, recording only a moderate RSB score (2.3). The combination of moderate RSB tolerance and probable drought resistance, in this low-rainfall provenance, suggests that it is a potential candidate for plantation establishment on, and use in tree breeding for, lower-rainfall sites. The remaining lower-rainfall provenances, Wondai, Gatton, Jandowae, Warwick and Carnarvon, all had higher RSB scores. The Carnarvon provenance, which is the westernmost and one of the driest natural occurrences of CCV, consistently recorded the highest incidence of disease, with very severe infection recorded on all the higher-rainfall sites.

The only improved seed source tested in this study was the imported South Africa seedlot from the South African Forestry Company Limited (SAFCOL) clonal seed orchard (CSO). At site 17, where RSB incidence was high, this provenance recorded the most severe damage of any of the three taxa and 28 spotted gum provenances examined in this study. Information is not available about the original genetic material from which this CSO was created and the seed selected. It is likely, however, that a large range of CCV and probably some CM provenances (both previously known as *Eucalyptus maculata*) were originally incorporated in this facility. The extremely poor RSB tolerance observed in this seedlot clearly demonstrates the hazards of importing seed from trees grown under greatly different climatic and environmental conditions to those of the target site. With RSB absent from this CSO, natural RSB tolerance would not be evident amongst individuals, and potential naturally-tolerant individuals may have been overlooked in this population in favour of individuals with other phenotypic characters suitable for the South African environment.

Ramularia shoot blight in *Corymbia citriodora* ssp. *citriodora*

The four CCC provenances from northern Queensland (Kirrama, Herberton, Mount Garnet and Hughenden) consistently recorded low RSB scores on the sites where they were tested. In particular, the Kirrama provenance of CCC, although represented only on low-rainfall sites, recorded very few symptoms of RSB. The Herberton provenance, which was represented on two sites (12 and 17) with very high RSB incidence, performed very well. On site 17, it was the only spotted gum provenance in this study to have a significantly lower RSB score than the Woondum provenance of CCV. The two CCC provenances from low-rainfall areas of northern Queensland (Mount Garnet and Hughenden) also performed well. On the two sites where it was represented, the Hughenden provenance of CCC recorded significantly lower RSB scores than the central Queensland CCC provenances of Calliope and Yeppoon (site 6) and Glendon (site 12).

Of the five central Queensland CCC provenances represented (Yeppoon, Gladstone, Calliope, Glendon and Biloela), the Gladstone provenance showed the greatest RSB tolerance. At the two higher-rainfall sites (15 and 18) where it was represented, the Gladstone provenance of CCC recorded a significantly lower RSB score than the Yeppoon provenance. The Biloela, Calliope and Glendon CCC provenances performed poorly, consistently having the highest RSB score amongst CCC provenances on the sites where they were represented.

Ramularia shoot blight in *Corymbia henryi*

The RSB scores for CH provenances across all sites were relatively uniform, except at site 6 where the Gatton provenance had a significantly higher score than the Myrtle Creek provenance. At sites of >800 mm MAR, very high levels of RSB infection were observed amongst all CH provenances, with no significant differences in the degree of tolerance. Of the five New South Wales provenances tested at site 22, the Myrtle Creek provenance performed the best, having the greatest height growth and the lowest RSB score. At site 17, the differences between the Gold Coast provenance and the Gatton provenance were not significant.

Tree height of all three taxa

As height measurements at a young age provide only a preliminary indication of potential tree growth, these results should be viewed with caution. In this study, variation in the early tree growth between provenances appears to be closely associated with the severity of ramularia infection, particularly at sites with >750 mm MAR where RSB was more common. In trials located in high-rainfall areas, the Woondum provenance was consistently amongst the tallest of the CCV provenances. The Brooyar, Veteran and Monto provenances of CCV also performed well at the sites where they were represented. For CCC, the Kirrama, Herberton and Mount Garnet provenances, which recorded the lowest RSB scores, also had the greatest height growth. For CH, there was little difference in height growth between provenances, a result which parallels the small differences observed between provenances for RSB tolerance.

Conclusions

The potential for RSB on a specific site is closely associated with local climatic conditions, and site MAR is a good indicator of the potential RSB risk. The incidence of RSB appears minimal on sites with <750 mm MAR, increasing markedly on sites with 750–800 mm MAR, and very common on sites with >800 mm MAR. It also appears that the MAR of the provenance origin is a good

[1]Johnson, I. Senior Scientist (Tree Improvement Program), Research and Development Division, State Forests of New South Wales, Sydney, NSW

indicator of the potential RSB-tolerance of an individual spotted gum provenance. For CCV, the three best-performing provenances (Woondum, Brooyar and Veteran) were from sites of >1000 mm MAR. The two best-performing provenances of CCC (Kirrama and Herberton) and CH (Gold Coast and Myrtle Creek) were all from sites of >1100 mm MAR.

Of the taxa and provenances tested, the Woondum provenance of CCV has consistently demonstrated high early growth rates and very good tolerance to RSB across a wide range of sites. At sites where RSB damage to other provenances was high, about 40% of the Woondum stems remained unaffected, with an additional 30% of stems recording only light damage with no impact on tree form. It is currently recommended that this provenance of CCV or other similarly tolerant provenances be selected for use in all proposed spotted gum plantations in southern Queensland where rainfall exceeds 800 mm. On sites with <800 mm rainfall, the Monto provenance with good growth and moderate RSB tolerance may be an alternative due to its suspected greater drought- and cold-hardiness.

On the limited number of sites where they were included, the Kirrima and Herberton provenances of CCC demonstrated good growth and very good tolerance to RSB. Currently these would be the preferred provenances for CCC plantation establishment. The Mount Garnet, Hughenden and Gladstone provenances of CCC also performed well and may be alternatives on drier sites, due to their suspected greater drought-hardiness. For CH, RSB was severe on sites with >800 mm MAR. Occasional good individuals were observed, however, within the higher-rainfall provenances from the Gold Coast and NSW (particularly Myrtle Creek).

At present, plantation establishment of the taxa CCV, CCC and CH is possible only with seed from natural provenances. The results from this study enable recommendations — provenances with demonstrated high tolerance of RSB and good growth at a young age — to be made for each of these taxa. Since 1997, the Queensland Department of Primary Industries has embarked on tree improvement programs for these three taxa, establishing throughout southern Queensland a number of provenance seedling seed orchards and breeding seedling seed orchards. Ongoing research should identify additional provenances (and families within provenances) with desirable growth and disease tolerance characteristics. It is envisaged that, within the next few years, increasing quantities of improved seed from seed orchards will become commercially available and will provide plantation growers with seed for trees with considerably greater RSB tolerance and growth potential than the trees in natural provenances from which the seed is currently derived.

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