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BIOMASS PARTITIONING IN *CORYMBIA CITRIODORA*, *EUCALYPTUS CLOEZIANA* AND *E. DUNNII* STOCK PLANTS IN RESPONSE TO TEMPERATURE

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TRUEMAN SJ, MCMAHON TV & BRISTOW M. 2013. Biomass partitioning in *Corymbia citriodora*, *Eucalyptus cloeziana* and *E. dunnii* stock plants in response to temperature. Production of subtropical eucalypt cuttings is limited by low temperatures but nothing is known about the effects of temperature variation on biomass partitioning within eucalypt stock plants. This study determined whether changing the temperature from 28/23 °C (day/night) to 18/13, 23/18 or 33/28 °C affected the distribution of biomass among the roots, pruned hedge and cuttings of *Corymbia citriodora*, *Eucalyptus cloeziana* and *E. dunnii* stock plants. Root/shoot ratio was significantly higher at 18/13 °C than at 33/28 °C, with the roots of the three respective species comprising 36, 50 and 37% of total plant biomass at 18/13 °C but only 24, 27 and 18% of total plant biomass at 33/28 °C. The responses to low temperature in the *Eucalyptus* species were highly unusual since root/shoot ratio was elevated at 18/13 °C because of an increase in root mass. Subtropical eucalypt stock plants divert biomass production from their shoots to their roots under conditions of low temperature. Thus, sustained cutting production may require that nurseries upgrade the climatic protection for stock plants during winter conditions.

Keywords: Adventitious roots, nitrogen, phosphorus, potassium, pot volume, propagation

TRUEMAN SJ, MCMAHON TV & BRISTOW M. 2013. Pengagihan biojisim dalam stok tanaman *Corymbia citriodora*, *Eucalyptus cloeziana* dan *E. dunnii* sebagai gerak balas terhadap suhu. Penghasilan keratan *Eucalyptus* subtropikal terhad oleh suhu rendah. Namun tiada apa yang diketahui tentang kesan perubahan suhu terhadap pengagihan biojisim dalam stok tanaman *Eucalyptus*. Kajian ini menentukan sama ada perubahan suhu daripada 28 °C/23 °C (siang/malam) kepada 18 °C/13 °C, 23 °C/18 °C atau 33 °C/28 °C memberi kesan terhadap pengagihan biojisim di kalangan akar, pucuk terpangkas dan keratan *Corymbia citriodora, Eucalyptus cloeziana* dan *E. dunnii*. Nisbah akar/pucuk lebih tinggi dengan signifikan pada 18 °C /13 °C berbanding dengan 33 °C/28 °C. Kandungan biojisim akar pada 18 °C /13 °C bagi ketiga-tiga spesies adalah masing-masing 36%, 50% dan 37% tetapi nilainya cuma 24%, 27% dan 18% pada 33 °C/28 °C. Gerak balas spesies *Eucalyptus* terhadap suhu rendah sangat luar biasa memandangkan nisbah akar/pucuk meningkat pada suhu 18 °C /13 °C kerana peningkatan jisim akar. Dalam keadaan suhu rendah, stok tanaman *Eucalyptus* subtropika mengalihkan penghasilan biojisim dari pucuk ke akar. Justeru itu, penghasilan keratan yang berkekalan mungkin memerlukan pihak tapak semaian meningkatkan perlindungan iklim bagi stok tanaman ketika musim sejuk.

INTRODUCTION

Propagation of cuttings is often difficult for woody plants but efficient vegetative propagation has been achieved for many species by optimising their stock plant environment, post-severance treatments and propagation conditions (Leakey 2004, Trueman et al. 2007, Pijut et al. 2011). Eucalypts, particularly those suited to dry-land environments, are often recalcitrant to propagation from cuttings. These include three of the most widely grown species in the subtropics, *Corymbia citriodora*, *Eucalyptus cloeziana* and *Eucalyptus dunnii*. These eucalypts are grown from seed or cuttings in Australia, India, China and Brazil for timber, pulp, essential oil and biofuel products. Plantation productivity has been limited by their low amenability to propagation and deployment as genetically-improved clones.

One of the constraints in vegetative propagation of subtropical eucalypts is seasonal

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variation in rooted cutting production (Assis et al. 2004, Trueman & Richardson 2008, Cunha et al. 2009). Eucalypt production nurseries often provide less climatic protection for stock plants than for cuttings (McNabb et al. 2002, Assis et al. 2004, Saya et al. 2008) and so the stock plants can be subjected to significant temperature and photoperiod variation across seasons. Optimal stock plant temperatures for rooted cutting production are 28–33 °C for *C. citriodora* and 33 °C for *E. cloeziana* and *E. dunnii*, with production declining markedly in all three species at lower temperatures (Trueman et al. 2013a, b). Shoot production is the primary determinant of rooted cutting production across temperatures for *C. citriodora*, while both shoot production and adventitious root formation are determinants of rooted cutting production across temperatures for *E. cloeziana* and *E. dunnii* (Trueman et al. 2013a, b).

The partitioning of biomass within stock plants has been described for *E. urophylla* (Neto et al. 2012). However, nothing is known about the effects of temperature on biomass partitioning within eucalypt stock plants despite the importance of shoot production in determining the final number of rooted cuttings. This study determined the distribution of biomass among roots, pruned hedge and cuttings of *C. citriodora*, *E. cloeziana* and *E. dunnii* stock plants at four temperatures. These results will assist in developing stock plant management strategies for vegetative propagation of these and other eucalypt species.

MATERIALS AND METHODS

Stock plants

Plants harvested in this study were a subsample from the rooted cutting study of Trueman et al. (2013a, b). Stock plants were raised by sowing seeds in January 2009 in a glasshouse in Gympie (26° 11' S, 152° 40' E). Seeds of *C. citriodora* subsp. *variegata* (Woondum State Forest, 26° 15' S, 152° 43' E) were obtained from Agri-Science Queensland. Seeds of *E. cloeziana* (Wolvi State Forest, 26° 07' S, 152° 46' E) and *E. dunnii* (Koreelah State Forest, 28° 18' S, 152° 30' E) were obtained from the Australian Tree Seed Centre. The seedlings were transplanted in February 2009 into 2.8 L pots filled with 75/25 (v/v) shredded pine bark/perlite. This potting medium included 3 kg of 8–9 month slow release Osmocote™ fertiliser, 3 kg of lime, 1 kg of gypsum, 1 kg of Micromax™ granular micronutrients and 1 kg of Hydroflo™ soil wetting agent incorporated per m^3. The seedlings were transferred into four controlled-temperature glasshouse chambers in Nambour (26° 38' S, 152° 56' E). Temperatures in all chambers were 28/23 °C (day/night, 0600–1800 hours/1800–0600 hours respectively). Irradiance was reported by Trueman et al. (2013a). The seedlings were then managed as hedged stock plants from April 2009 by pruning and harvesting cuttings at 3-week intervals to ~30 cm plant height and ~20 cm canopy diameter.

Experimental design

Temperatures in three of the chambers were changed randomly on 15 June 2009 to provide four treatments across the four chambers: 18/13, 23/18, 28/23 and 33/28 °C (day/night, as described above). The four treatments were, henceforth, termed 18 °C, 23 °C, 28 °C and 33 °C respectively. Temperatures and their corresponding stock plants were randomly relocated to a different chamber every 4 weeks to minimise the effects of chamber.

Three stock plants of each species were destructively sampled from each chamber on 21 September 2009 (14 weeks after commencement of temperature treatments). All available cuttings were harvested from each stock plant and the remainder of the stock plant was dissected into roots and hedge. The roots were rinsed gently in water to remove potting mix. The three plant parts (roots, hedge and cuttings) were placed in separate paper bags, dried for 7 days at 65 °C and weighed. The cuttings were ground and concentrations of N, P and K were determined by combustion analysis or inductively-coupled plasma–atomic emission spectroscopy (Trueman et al. 2013a, b). Total plant mass, proportions of total mass contained in each of the three plant parts and the root/shoot ratio were calculated for each stock plant.

Statistical analyses

All data were analysed by analysis of variance (ANOVA), comparing four temperatures within each species. Post-hoc least significant difference (LSD) tests were performed only when significant differences were detected by ANOVA. Masses and nutrient concentrations were square root or log transformed, and proportions were arcsine square root transformed when variance was heterogeneous. Means were reported with standard errors and treatment differences were regarded as significant at $p < 0.05$.

RESULTS AND DISCUSSION

Dry mass of cuttings and hedge did not differ significantly between the four temperatures for *C. citriodora* or *E. dunnii* (Figures 1a and b). However, hedge dry mass was lower at 23 than at 33 °C for *E. cloeziana* (Figure 1b). Cutting dry mass in the current study only represented shoot production from 11–14 weeks after stock plant temperatures were changed from 28 °C, as the stock plants were harvested for cuttings every 3 weeks. At this stage, shoot production was declining as some foliar nutrient levels began to decline (Trueman et al. 2013a, b). Cumulative production of cutting biomass (over 15 weeks) was highest at 28 and 33 °C for all three species (Trueman et al. 2013a, b).

Root dry mass was significantly higher at 18 than at 28 or 33 °C for *E. cloeziana* and at 33 °C for *E. dunnii* but not significantly different at 18 °C than from any other temperature for *C. citriodora* (Figure 1c). Root dry mass increased from 4.5 ± 1.7 g at 33 °C to 9.3 ± 2.7 g at 18 °C in *E. cloeziana* and from 1.9 ± 0.7 g at 33 °C to 4.5 ± 1.3 g at 18 °C in *E. dunnii*, representing increases in dry mass of 107 and 137% respectively. Total plant mass did not differ between temperatures for *C. citriodora* or *E. dunnii* but stock plants grown at 28 °C were significantly lighter than those at 18 °C for *E. cloeziana* (Figure 1d). Growth of potted plants typically becomes limited when the plant biomass to pot volume ratio exceeds 2 g L^{-1} (Poorter et al. 2012). Total plant mass in the current study ranged from 9.5 ± 3.1 g (*E. dunnii* at 33 °C) to 18.4 ± 7.5 g (*C. citriodora* at 33 °C). The pot volume was 2.8 L. Therefore, pot volume ratio had greatly exceeded 2 g L^{-1} in all three species within 8 months of germination. Pot volumes of < 3 L are often used for eucalypt stock plants and so productivity is likely to be rapidly limited by pot size in many commercial nurseries.

The allocation of biomass to cuttings and to the hedge, as proportions of total plant mass, did not differ significantly between temperatures (Figures 2a and b). Nonetheless, the proportion of total plant biomass contained in the root system was significantly higher at 18 than at 33 °C for *C. citriodora* and significantly higher at 18 than at 28 and 33 °C for *E. cloeziana* and *E. dunnii* (Figure 2c). In these three respective species, roots comprised 36 ± 2, 50 ± 3 and 37 ± 3% of total plant biomass at 18 °C but only 24 ± 5, 27 ± 4 and 18 ± 2% at 33 °C. Root/shoot ratio

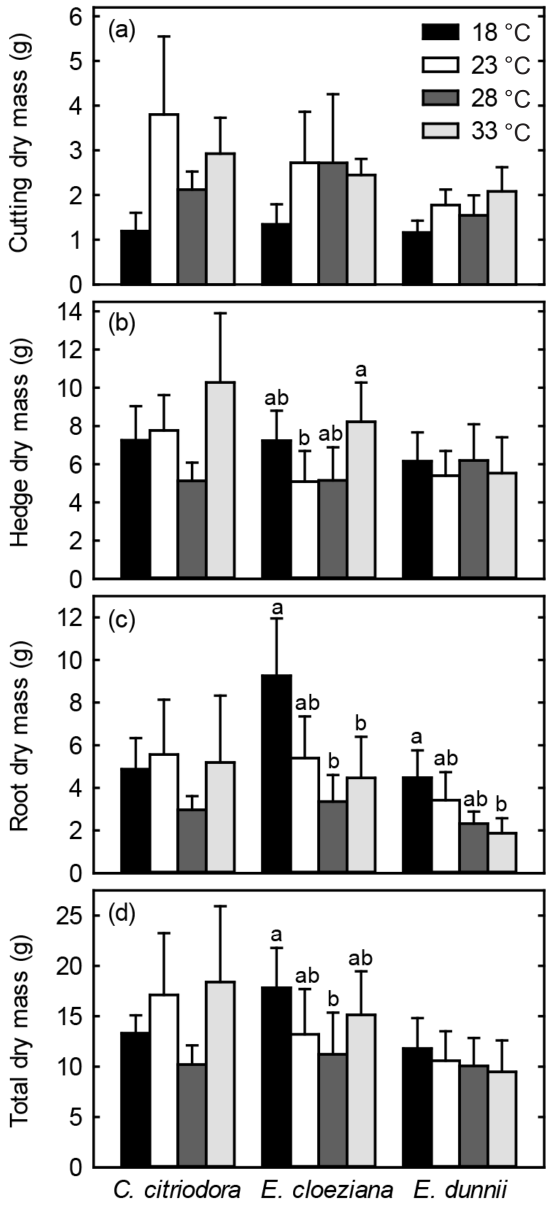

Figure 1 Dry mass of (a) cuttings, (b) hedge, (c) roots and (d) whole plant for *Corymbia citriodora*, *Eucalyptus cloeziana* and *E. dunnii* stock plants grown at 18, 23, 28 or 33 °C; means with different letters within a species are significantly different (ANOVA and LSD test, $p < 0.05$, n = 3)

was significantly higher at 18 than at 33 °C for *C. citriodora* and significantly higher at 18 than at 28 and 33 °C for *E. cloeziana* and *E. dunnii* (Figure 2d).

Plants respond to abiotic stresses by allocating biomass to those organs that are involved in acquiring the scarcest resources, maximising their relative growth rate (Ågren & Franklin 2003). Low temperatures—particularly 18 °C and lower—can reduce water uptake and subject the aboveground parts of the plant to nutrient deficiencies (Poorter et al. 2011). An increase in root/shoot ratio is a common response to both low temperature (Wu & Zou 2010, Franco et al. 2011, Poorter et al. 2011) and deficiencies of N or P (Hermans et al. 2006, Franco et al. 2011). Greater biomass allocation to root growth enables plant to maintain optimal levels of N and P in the aboveground parts (Vance et al. 2003, Hermans et al. 2006). In the current study, N, P and K concentrations in the cuttings did not decline at 18 °C for any of the species (Figure 3). Root/shoot ratio is elevated in other species because of a decrease in shoot mass rather than an increase in root mass (Wu & Zou 2010, Franco et al. 2011). However, responses to low temperature in the two *Eucalyptus* species of the current study were unusual because root/shoot ratios were elevated at 18 °C due to an increase in root mass. Optimal temperatures for long-term shoot production by *E. cloeziana* and *E. dunnii* are 28–33 °C (Trueman et al. 2013a, b), as are the optimal temperatures for light-saturated photosynthesis in *E. cloeziana* and another subtropical species, *E. argophloia* (Ngugi et al. 2003). Higher root growth of the *Eucalyptus* species at 18 °C appears to be an adaptive response to ensure uptake of adequate nutrients for optimising whole plant growth during periods of low temperature (Ågren & Franklin 2003, Hermans et al. 2006).

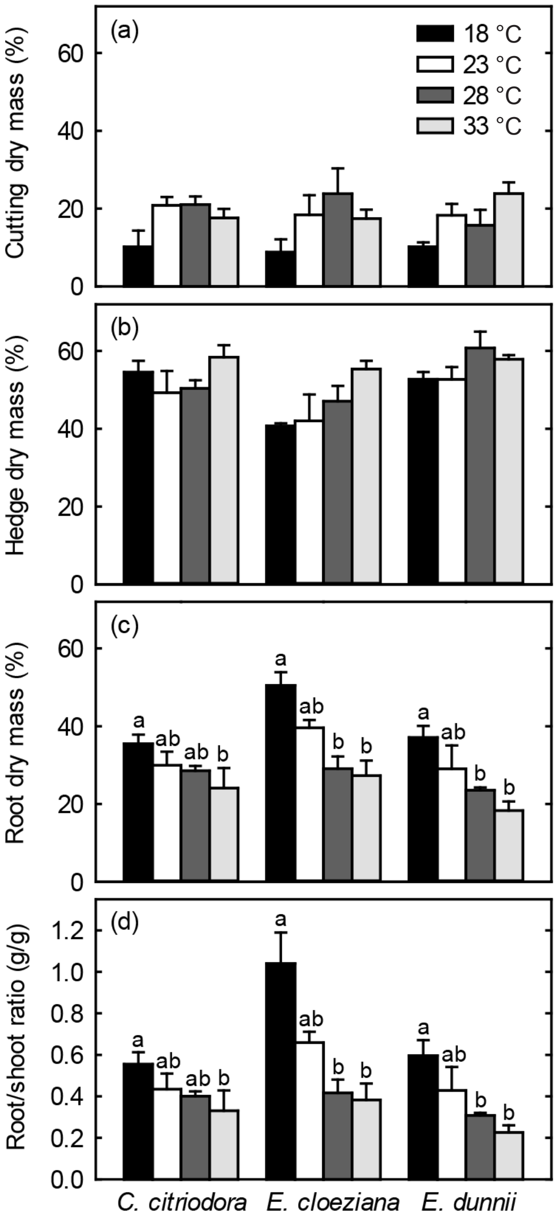

Figure 2 Percentages of total plant mass contained in (a) cuttings, (b) hedge and (c) roots and (d) root/shoot ratio for *Corymbia citriodora*, *Eucalyptus cloeziana* and *E. dunnii* stock plants grown at 18, 23, 28 or 33 °C; means with different letters within a species are significantly different (ANOVA and LSD test, $p < 0.05$, n = 3)

In conclusion, results from this study, when combined with results on cumulative cutting production from Trueman et al. (2013a, b), demonstrated that subtropical eucalypt stock plants diverted biomass production from their shoots to their roots under conditions of low temperature. This response maintained the growth rate of the whole plant but reduced the production of rooted cuttings. Stock plant temperature strongly affected the ensuing percentages of cuttings that form roots in *E. cloeziana* and *E. dunnii*, but not in *C. citriodora* (Trueman et al. 2013a, b). Sustained plant production of subtropical eucalypts throughout the year requires that nurseries upgrade the climatic protection provided to stock plants during winter, with the aim of maintaining temperatures as close as possible to the optimum (28–33 °C) for photosynthesis and shoot production.

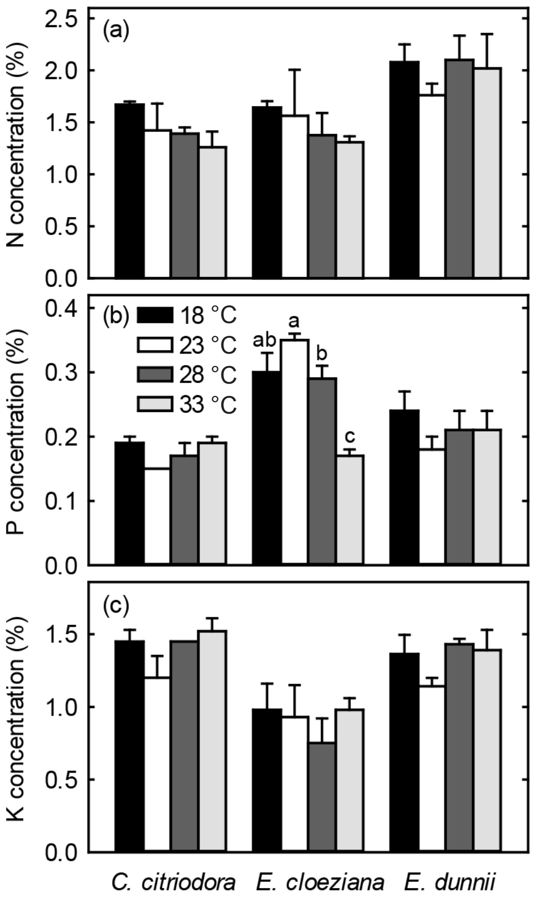

Figure 3 Concentrations of (a) N, (b) P and (c) K in the cuttings of *Corymbia citriodora, Eucalyptus cloeziana* and *E. dunnii* stock plants grown at 18, 23, 28 or 33 °C; means with different letters within a species are significantly different (ANOVA and LSD test, $p < 0.05$, n = 3)

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