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The cutting depth required to control calotrope (*Calotropis procera*) plants using mechanical techniques

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Abstract. Calotrope (*Calotropis procera* (Aiton) W.T. Aiton) is an exotic woody weed that has invaded northern Australia's rangelands since being introduced in the early 1900s. To expand the range of control options beyond herbicide-based methods, we undertook a stem/root cutting experiment that helped quantify the potential for using mechanical control techniques. Individual, medium-sized (1.72 ± 0.03 m high) calotrope plants were cut off at ground level (0 cm) or below ground (10 or 20 cm) using either a pruning saw or mattock respectively. All calotrope plants cut at ground level reshot vigorously. After four months they had more than twice the number of stems (7.4 ± 0.54) of the uncut control plants and by 12 months they were only 26 cm shorter than the control plants. In contrast, all plants cut at 10 or 20 cm below ground were killed. Some mortality also started occurring in the control and ground level (0 cm) treatments after eight months, but appeared to be associated with a dieback phenomenon. Nevertheless, the results demonstrate the potential to use equipment that severs the root system below ground, such as blade ploughs and cutter bars. A subsequent stick raking demonstration achieved moderate plant mortality (72%) after 13 months, yet produced a six-fold increase in original plant density as a result of new seedling emergence. This finding supports the view that mechanical disturbance will often promote seedling recruitment, and land managers need to have the capacity to undertake follow-up control practices to avoid exacerbating the problem.

Additional keywords: invasive species, rangeland management, rubber bush, woody weed.

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Introduction

Calotropis procera (Aiton) W.T. Aiton, most commonly known as calotrope or rubber bush, is a native of tropical and subtropical Africa and Asia (Rahman and Wilcock 1991). It is believed to have been introduced into Australia sometime in the early 1900s either for ornamental purposes or in the packing used for camel saddles (Parsons and Cuthbertson 2001). Since then it has spread across large areas of northern Australia, yet it still only occupies a small proportion of its potential range, which includes most of the rangelands of northern Australia (Grace 2006; Csurhes 2009; Campbell *et al.* 2015; Menge *et al.* 2016*b*). Expansion of its potential range is expected in the face of future climate change, particularly into northern regions of Queensland and Western Australia (Menge *et al.* 2016*b*).

Distinguishing features of calotrope include large rounded leaves that have a waxy appearance and grey-greenish colour, flowers that are white with distinctive purple blotches at the tips, bladder-like pods that split open to release white-plumed seeds and a milky sap (latex) that is released from plant parts when damaged (Grace 2006; Smith 2011). Plants can grow up to 6 m in size as a spreading shrub or small tree and they can have single or multiple stems (Vitelli *et al.* 2008). The root system is also extensive, comprising a taproot capable of growing 3–4 m in length, with some lateral roots branching off it (Parsons and Cuthbertson 2001).

Thick infestations of calotrope are thought to have a negative impact on production and biodiversity (Grace 2006). Some people believe it is a highly competitive plant capable of replacing pastures in good condition, while others consider it a weed of disturbed or degraded areas (Bastin *et al.* 2003; Grace 2006). More recently, Menge *et al.* (2017) showed that calotrope does not readily invade intact grassland dominated by native Mitchell grass (*Astrebla pectinata* (Lindl.) Benth.). The authors also demonstrated that calotrope seedling emergence is five times greater in sites subjected to disturbance. Factors associated with soil disturbance (i.e. distance to minor roads and beef cattle stocking density) have been identified as good predictors of calotrope distribution (Menge *et al.* 2016*b*). The plant contains toxic compounds, although there are few reports of domestic animals dying from it (Grace 2006). At times, animals will even heavily graze calotrope plants and this may help keep them in check (Grace 2006).

One of the limitations to preventing the spread of calotrope has been a lack of effective and economical control options, particularly for extensive infestations in pastoral situations (Cheam 1984). Grace (2006) highlighted the paucity of control techniques, and research into cheaper control options for larger areas was identified as a priority in a research prioritisation process undertaken for the dry tropics of northern Queensland (Bebawi *et al.* 2002).

In more recent years, the findings of several research trials to improve herbicide control options for calotrope have been published (Vitelli *et al.* 2008) and used to support minor use and label registrations to allow landholders to use these more effective herbicide options legally. Although herbicide control techniques have improved, the use of mechanical techniques has not been formally trialled on calotrope. It has been suggested that small infestations or individual plants can be controlled if at least 25–30 cm of the taproot and as many lateral roots as possible are removed (Parsons and Cuthbertson 2001). Less damaging treatments such as the use of shallow ploughs have been reported to be ineffective, with extensive regrowth occurring from the plant's spongy tuberous root system (Grace 2006).

This paper reports on a study aimed at quantifying the level of damage necessary to achieve high mortality of calotrope. This involved a root cutting experiment, where the plant taproot was cut off at different depths below ground. A demonstration site was also established to observe the effects of stick raking on plant mortality and seedling recruitment. The results will help land managers considering using machinery to control calotrope in northern Australia. Knowing the cutting depth needed to kill calotrope plants will enable them to select suitable equipment capable of causing high mortality.

Materials and methods

Site details

A field site was selected on a cattle property in the Gulf of Carpentaria Region, north-west Queensland (18°56′46.5″S, 140°31′12″E). It covered ~0.5 ha and contained a medium density stand of calotrope that was growing in between gidgee regrowth (*Acacia cambagei* R.T. Baker) that averaged ~2–3 m in height. The general landform is flat to gently sloping, undulating plains with gilgai (small depressions) development throughout. The soils are primarily shrinking and expanding cracking clays with scattered surface gravel or light stone cover. The understory is sparse and dominated by *Aristida* spp., *Chloris* spp., *Enteropogon* spp. and the occasional *Astrebla* spp.

The long-term mean annual rainfall for the site, based on the closest official Bureau of Meteorology rainfall monitoring station, is 762 mm (Bureau of Meteorology 2015). For the first 12 months of the cutting depth experiment (October 2011–September 2012) this was exceeded by ~100 mm, but the second 12 months (October 2012–September 2013) was very dry, with only 420 mm recorded (Queensland Government 2015).

Cutting depth experiment

An experiment comprising four treatments in a completely randomised design was initiated at the site on 7 October 2011. Treatments comprised an untreated control (not cut) and three root cutting depths (0 cm – level with the soil surface, and 10 and 20 cm below ground level).

Experimental units were individual rubber bush plants spaced at least 2 m apart, with each treatment replicated 15 times. Prior to treatment application, plants were tagged and their height and basal diameter were recorded.

A mattock was used to sever the roots for the below-ground cuts (i.e. 10 and 20 cm) and a forestry-type pruning saw was used to cut stems level with the ground surface for the 0 cm treatment. Both treatments resulted in a smooth cut through the relatively soft stems and roots of the medium-sized calotrope plants. Once treatments were implemented, the exact depth where cuts were made was measured and averaged. The 10 and 20 cm below ground treatments averaged 11.2 ± 0.55 cm and 19.0 ± 0.36 cm respectively.

Post-treatment mortality assessments were undertaken four (1 February 2012), eight (26 June 2012), 12 (30 October 2012), 16 (11 February 2013), 21 (27 July 2013) and 24 (27 October 2013) months after treatment (MAT). If plants were alive, additional data were recorded on the number of living stems, plant height and whether any flowers or pods were present.

Stick raking demonstration

In February 2012, a stick rake (~5 m wide) fitted to a large front end loader was used to clear ~5 ha of dense rubber bush near to the experimental site. To estimate the efficacy of this technique, a 25×25 m monitoring area was demarcated within the 5 ha area, two weeks before treatment application. Plant location (relative to a fixed reference point), height and basal diameter were then recorded for all plants in the 25×25 m area. Post-treatment assessments were undertaken five (July 2012), 10 (December 2012) and 13 MAT (March 2013) to quantify the level of mortality of original plants and the amount of seedling regrowth. Observations of flowering and podding were also made during post-treatment assessments.

Statistical analysis

For the cutting depth experiment, GENSTAT was used to analyse individual tree survival data using a Generalised Linear Model based on binomial proportions (GENSTAT 16, VSN International, Hemel Hempstead, Hertfordshire, UK). Post treatment growth responses (height and number of stems) of treatments that did not directly kill plants (i.e. control and 0 cm) were compared using the analysis of variance function in GENSTAT.

Results

Cutting depth experiment

Prior to treatment application, there was no significant size difference ($P > 0.05$) between plants assigned to the different cutting treatments. On average, they had 2.9 ± 0.3 (mean ± s.e.) stems and were 1.72 ± 0.03 m high with an average basal diameter of 7.63 ± 0.16 cm.

After treatments were applied, cutting location had a significant ($P < 0.05$) effect on the mortality of calotrope plants. All

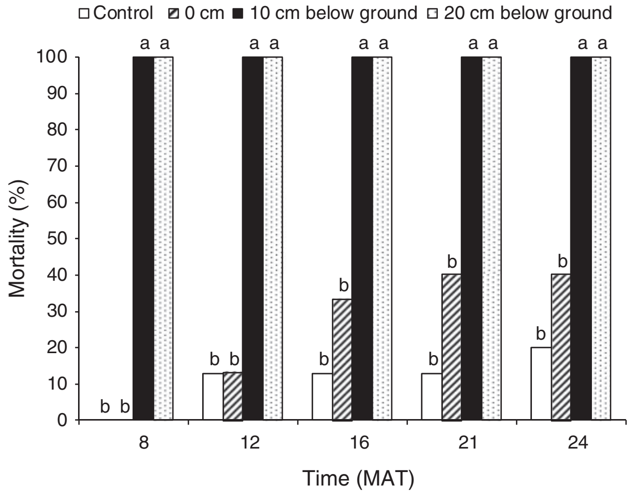

Fig. 1. The effect of cutting depth on mortality (%) of calotrope plants eight, 12, 16, 21 and 24 MAT. Within each assessment time, bars with the same letters are not significantly different ($P > 0.05$).

plants cut at ground level reshot after treatment, while all plants cut at 10 or 20 cm below ground were killed (see eight MAT in Fig. 1). Some mortality of control and 0 cm plants occurred from eight MAT (October 2012) onwards and coincided with the appearance of a dieback phenomenon during this time. Nevertheless, 24 MAT there were still significant differences in mortality, with the 10 and 20 cm below ground treatments averaging 100% mortality, compared with ≤40% in the control and 0 cm treatments (Fig. 1).

Cutting plants off close to ground level caused them to reshoot vigorously, the number of stems reaching 7.4 ± 0.54 (four MAT). This was more than twice the number of stems on control plants at the same time (Fig. 2). The height of cut plants also increased rapidly, and by 12 MAT they were only 26 cm shorter than untreated control plants (Fig. 2). At eight MAT all cut plants were flowering again and by 12 MAT a small percentage (15%) were podding.

The impacts of the dieback phenomenon resulted in a rapid reduction in plant height in both the control and 0 cm treatment from 12 MAT onwards. Plants responded to the dieback by reshooting vigorously from the base (mainly between 12 and 16 MAT), but many of these stems eventually died. By 24 MAT, the average number of live stems per plant was below two for both control and 0 cm treatments (Fig. 2).

Stick raking demonstration

Five months after stick raking was undertaken, 28% of the original plants remained alive and had reshot from the base after being cut off close to ground level. These plants exhibited rapid regrowth and by 13 MAT their mean plant height was the same as that recorded before stick raking (Table 1). No further plants had re-shot by this time, suggesting a plant mortality rate of 72% had been achieved.

Basal diameter of surviving plants was not significantly different ($P > 0.05$) to that recorded before treatment and did not change with evaluation time (Table 1). However, surviving plants appeared to have more stems following treatment. Prior to stick raking, plants were generally observed to have between one and three stems (data not recorded), whereas mean stem number post-treatment was 5.2 or more and did not significantly differ ($P < 0.05$) between evaluation times (Table 1). Flowering and pod production 13 MAT was observed in 50 and 8% of surviving original plants, respectively.

Calotrope plant density five MAT was more than four times the initial density as a result of new seedling emergence (Figs 3, 4). Plant density increased over time and reached

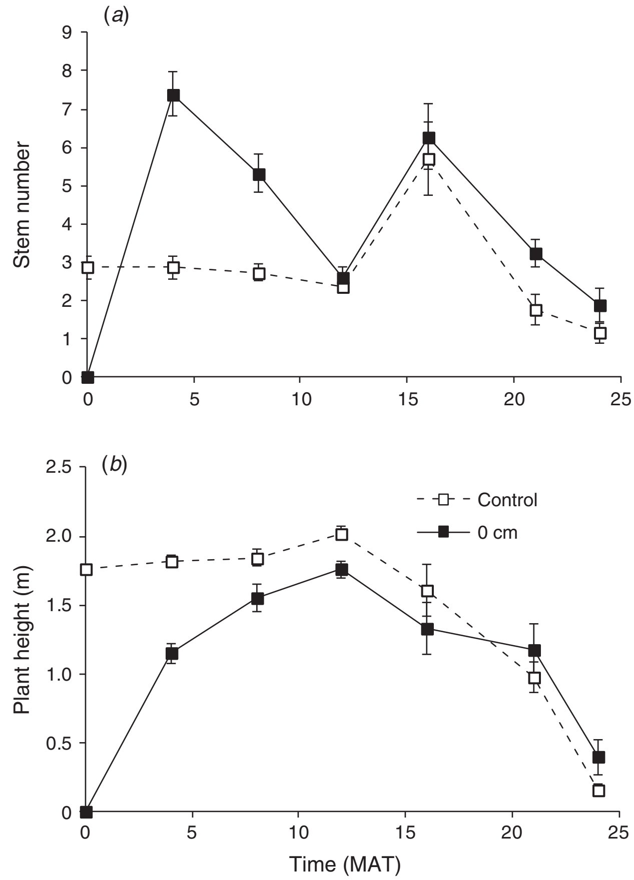

Fig. 2. Changes in (*a*) number of stems and (*b*) plant height for live control calotrope plants and those cut off at ground level (0 cm treatment). Vertical bars represent the s.e.

Table 1. Morphology of original calotrope plants two weeks before stick raking (pre-treatment) and five, 10 and 13 months after treatment (MAT)

Means within a column that do not share a letter are significantly different ($P < 0.05$) according to Fisher's l.s.d. test; nd, not determined

Evaluation time (MAT)	*n*	Plant height (m)	Basal diameter (cm)	Stem no.
Zero (pre-treatment)	32	1.11a	5.8a	nd
Five	9	0.38b	5.1a	7.8a
10	10	0.90ab	6.7a	5.2a
13	9	1.23a	7.3a	5.2a

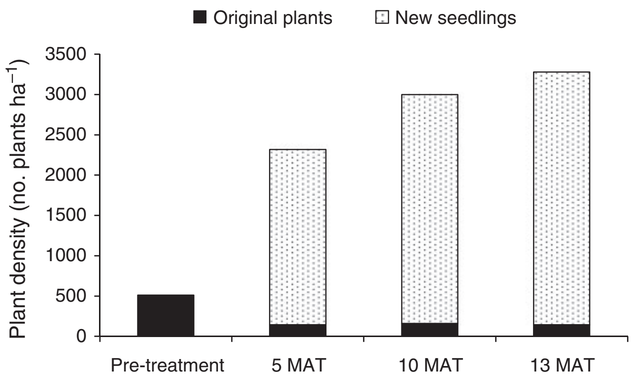

Fig. 3. Calotrope plant density two weeks before stick raking (pretreatment) and five, 10 and 13 months after treatment (MAT).

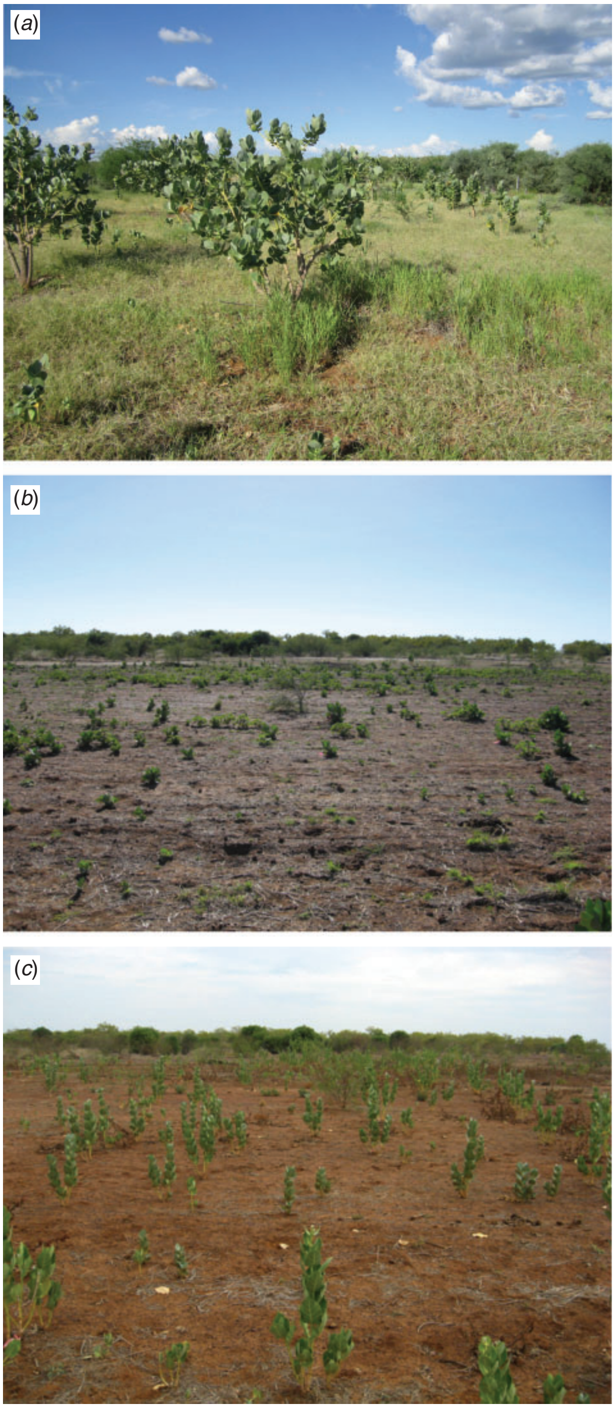

Fig. 4. Calotrope stick raking demonstration site (*a*) two weeks before treatment, (*b*) five months after treatment and (*c*) 10 months after treatment.

3280 plants ha^{-1} by 13 MAT, more than six times the original density of 512 plants ha^{-1}. New seedlings were generally 30–75 cm in height by this time. Monthly rainfall records for the site during the experimental period were matched to the treatment and evaluation times (Fig. 5) to provide better understanding of seedling emergence behaviour. Substantial rainfall occurred immediately after stick raking, as well as between the 10 and 13 MAT evaluation times.

Discussion

This study has confirmed the potential for using mechanical techniques for calotrope control if the root system is severed below the soil surface. The findings are consistent with the earlier recommendation of Parsons and Cuthbertson (2001) who suggested that mechanical control can be effective if at least the top 25–30 cm of the root system is removed. However, at least for small to medium-sized plants, they may not need to be cut off so deeply. Depths of 10–20 cm in the current study achieved 100% mortality.

The ability to use machinery provides an additional option to herbicides and can be comparable or cheaper in cost particularly as the density of woody weeds increases (McKenzie *et al.* 2004; Bebawi *et al.* 2011). Many landholders in northern Australia own or have access to machinery such as bulldozers, front end loaders and tractors, all of which could be used on calotrope, provided they have attachments that can cut plants off at the desired depth below ground. Alternatively, removing the whole plant including the root system would also be expected to cause high mortality, but would take more time to do properly and therefore would be more applicable to small areas, or isolated plants. Slashing or mulching have been relatively effective on some woody weeds, such as bellyache bush (Bebawi and Campbell 2002; Bebawi *et al.* 2011). However, for calotrope such treatments would most likely be ineffective due to an inability to damage plants below ground level. Stick raking, which severs plants at or slightly below the soil surface, produced only moderate mortality (72%) in the current study. We have also observed minimal mortality and extensive plant regrowth of calotrope following grading of fence lines where plants were cut off close to the surface. This is similar to anecdotal evidence reported by Grace (2006) for shallow ploughing. The use of cutter bars and blade ploughs that can sever plants off below ground at the required depth are likely to provide much higher mortality as reported for parkinsonia, another medium-sized woody weed in the rangelands of northern Australia (McKenzie *et al.* 2004).

The rapid regrowth of calotrope that occurs after treatment is another downside of ineffective mechanical treatment, with

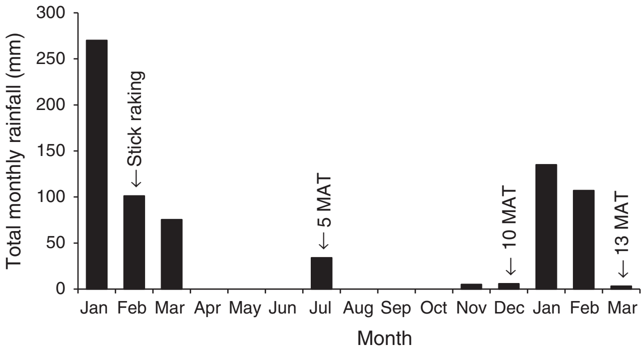

Fig. 5. Total monthly rainfall during the 2012–13 calotrope stick raking demonstration trial, based on the closest official Bureau of Meteorology rainfall monitoring station (Bureau of Meteorology 2012). Timing of stick raking treatment and site evaluation five, 10 and 13 months after treatment (MAT) are highlighted.

plants not only capable of reaching their pretreatment height within ~12 months, but with many more stems than they would have had otherwise. Consequently, follow-up control may be more challenging, particularly using techniques that are applied to the stem of plants. For example, basal barking is effective for control of calotrope (Vitelli *et al.* 2008; Campbell *et al.* 2015), but an increase in the number of stems to be sprayed may make it more difficult to obtain high mortality.

Fresh calotrope seeds can exhibit ≥ 98% viability and remain quiescent during periods of water stress or temperatures above 40°C (Menge *et al.* 2016*a*). Under moist soil conditions, seeds on the soil surface failed to germinate but readily did so at planting depths of 3 or 6 cm (Menge *et al.* 2016*a*). Hence, the disturbance created by mechanical techniques, particularly those undertaken on a broad-scale to treat dense infestations of woody weeds, can promote large - scale seedling recruitment (Vitelli 2000; Vitelli and Pitt 2006; Bebawi *et al.* 2011). It is therefore critical that land managers plan for this occurrence, because if they cannot undertake the necessary follow up, mechanical control can exacerbate the problem and rapidly increase the density of populations. The stick raking demonstration highlighted the capacity for seedling recruitment, with the population increasing 6-fold 13 months after treatment. However, promotion of seedling emergence of weeds can be highly advantageous if follow up control is undertaken before these plants reach reproductive maturity. It can allow more rapid depletion of soil seed reserves resulting in shorter timeframes to achieve overall control, provided there is no seed replenishment occurring from external sources (Campbell and Grice 2000).

Calotrope does not appear to have a long lived seed bank (Bebawi *et al.* 2015). A seed longevity trial found that the soil seed bank was exhausted within two years, as the seeds were highly germinable and large scale germination occurred under favourable environmental conditions (e.g. rainfall and temperature; Bebawi *et al.* 2015). In the present study, such favourable conditions were evident at the time of stick raking and were likely responsible for the rapid emergence of seedlings five MAT. The slower rate of seedling emergence observed after this time, despite good rainfall occurring between 10 and 13 MAT, supports the view that calotrope seeds are highly germinable and that the seed bank would have been largely depleted towards the end of the trial. Consequently, if land managers can treat all reproductive calotrope plants and undertake follow-up control frequently enough to kill new plants before they produce fruits, they should be able to control calotrope in an area within a two to three year time frame. This time frame could be longer if conditions have been dry and not conducive to germination, and if further seed input is occurring from external sources (i.e. through wind or water dispersal from neighbouring infestations), necessitating the need for ongoing control activities.

In terms of frequency of follow-up control, calotrope takes a minimum of 13 months to produce pods under favourable growth conditions (Bebawi *et al.* 2015), so annual treatment should be sufficient if land managers are confident that they can find all calotrope plants. If the vegetation and/or terrain make it difficult to find plants, six-monthly treatments will provide two opportunities to find them before they reach reproductive maturity.

The appearance of a dieback phenomenon during the course of the cutting depth experiment not only affected the results obtained but also demonstrated its potential to adversely affect the growth and survival of calotrope. The exact cause of the dieback has not been confirmed at this stage, but Wilkinson *et al.* (2005) did record the presence of a new leaf spot disease of calotrope (*Passalora calotropidis* (Ellis & Everh.) U. Braun) in Australia which displays similar symptoms to those found on plants in the present study. In a laboratory study, pathogens isolated from stem sections of calotrope were capable of killing inoculated calotrope seedlings (Isahak 2013). This highlights the need for further research to confirm the causal agent(s) and to consider whether it could be developed and utilised as a control option in its own right. Irrespective, at sites where it is present and prevails, it would most likely complement any mechanical control techniques as it appears to greatly reduce flowering and podding of affected plants. If the pathogen has been present at a site for a few years or more, the level of seedling regrowth after mechanical techniques may be greatly reduced.

In conclusion, this study has highlighted the ability to control calotrope using mechanical methods. However, land managers need to be able to control subsequent large scale seedling regrowth if it occurs. Future research that compares various mechanical techniques at different densities of calotrope and that also identifies the most appropriate follow up treatments would be beneficial for land managers considering the use of machinery.

Conflicts of interest

The authors declare no conflicts of interest.

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