

DRAFT PROCEEDINGS

23rd Biennial Australian Rangeland Society Conference

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7-11 September 2026

Darwin, Northern Territory

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Publisher: Australian Rangeland Society

Draft Proceedings of the 23rd Biennial Australian Rangeland Society Conference, Darwin, 2026



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The assistance of many colleagues not listed here is gratefully acknowledged.

Example suggested citation:
Bastin GN, Cowley RA (2026) Reduced landscape leakiness shows recovery of formerly degraded rangeland in the Victoria River District, Northern Territory. In: 'Managing Country for Cattle, Culture, Conservation, Carbon. Proceedings of the 23rd Australian Rangeland Society Biennial Conference, Darwin'. (Eds G. Bastin, D. Walsh, S. McDonald, M. Friedel, I. Watson, A. Liedloff) 5 pages. (Australian Rangeland Society: Darwin, NT)

Stem injection herbicide treatments for controlling neem trees.

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Key words: invasive; stem implantation; weeds; drill and fill; encapsulated herbicides

Abstract
Azadirachta indica A. Juss, (neem trees) tolerate hot, dry conditions and have become widely invasive across northern Australia. To investigate more options to control this weed, a replicated trial was conducted to assess the control efficacy of stem injected herbicides. Using a cordless drill, ten herbicides were applied as either liquid solutions or encapsulated granules injected into the base of trees and a maximum rate of one injection per 15 cm of circumference. In each injection interval, one concentrated herbicide capsule or 2 mL of a concentrated liquid herbicide solutions (drill and fill) were applied. Three liquid herbicides solutions were highly effective (>98%). Two encapsulated herbicide products were also >95% effective. These five treatments matched the efficacy of a reference basal bark treatment but used much less herbicide. The efficacy of other liquid or granular treatments was higher when injected at smaller circumference intervals, or in smaller trees. The trial data showed *A. indica* is controlled by multiple encapsulated herbicides and drill and fill liquid herbicide solutions. Stem injected herbicides are an effective and additional treatment option for individual *A. indica* trees.

Introduction

Azadirachta indica A. Juss, (neem tree) has been widely planted around the world for its many uses and has wide climatic tolerance of hot and dry conditions (CABI 2016). In northern Australia, *A. indica* is naturalised across three states and territories and has become a major environmental threat to the native riparian flora (Brooks *et al.* 2025, Pasfield 2008). There are dense infestations around Katherine and many other towns and rivers including the Wickham River in the Northern Territory and Gilbert River in Queensland (Brooks *et al.* 2025). Infesting at least 7100 ha of the Kununurra region of Western Australia (Pasfield 2008), *A. indica* was the highest priority for regional control due to agricultural, environmental and cultural damage (Miller and Beams 2018). *Azadirachta indica* is a declared weed in Western Australia due to damage to riparian habitats, threats to endangered animals, reducing access to agricultural infrastructure and impeding mustering (Western Australia 2022).

Across Queensland, the Northern Territory and Western Australia there are broad weed control recommendations for controlling *A. indica*, including 'stem injection' techniques. A new weed control technique uses dry encapsulated herbicides implanted into woody weeds and vines (Goulter *et al.* 2018, Miller and Beams 2018). Initial observations of encapsulated herbicides to *A. indica* trees found metsulfuron, imazapyr, glyphosate and triclopyr + picloram capsules effectively controlled between 25 and 30 neem trees per herbicide 12 months after application (Miller *et al.* 2019). Their observations showed that *A. indica* are susceptible to this treatment method and they identified advantages such as easier use and less protective equipment requirements over other methods tested.

A study by Silayo and Kiwango (2010), found stem injection with glyphosate to be an effective control method for *A. indica*. Recently a stem injection technique using a cordless drill to deliver herbicide solutions (liquid 'drill and fill') into the outer cambial layers of stems has been tested (Brazier *et al.* 2024, Brazier *et al.* 2025). The cost and ease of drill and fill herbicide applications on *Leucaena leucocephala* (Lam.) de Wit. was noted by Brazier *et al.* (2024).

As published herbicide trials on *A. indica* are limited, a trial was conducted to compare the effectiveness of five active ingredient combinations of encapsulated herbicides (Di-Bak), five liquid herbicide solutions (drill and fill method) and a standard basal bark method to control individual *A. indica* trees.

Methods

A field trial was established in the road corridor beside Days Road, Gumlu (S19° 52', E147° 41') on the seasonally dry tropical coast of northeastern Queensland. The trial utilised a randomised design initially

consisting of 12 treatments (11 herbicide formulations and one untreated control) with three replicates per treatment. Each plot contained 15 single-stemmed trees.

On 8/6/23, five encapsulated granule treatments were applied using an Injecta 400 applicator (Goulter *et al*. 2018, Miller *et al.* 2019). On 9/6/23, two liquid drill and fill treatments (Tordon® Regrowth Master and WeedMaster® Duo) and one reference basal bark treatment (Access® in diesel) were applied. On 28/6/23, an additional three liquid drill and fill treatments were established (Garlon®, Komachi®, and Tordon® 75-D). Herbicide active ingredients and application rates are detailed in Table 1.

For all liquid drill and fill treatments, an 8 mm bit on a cordless drill was used to drill injection points (Brazier *et al.* 2024). A 2 mL dose of the concentrated liquid solution was placed into each 4 cm deep drilled hole using a Spot Gun (Velpar® applicator) and 5 L backpack. The reference basal bark treatment was applied using a Swissmix® 9 L compression sprayer, wetting the entire stem circumference from ground level to a pre-marked height of 30 cm. One untreated plot per replicate served as a control.

All stem injection treatments were applied as close to ground level as practicable and below any stem forks. One capsule or a 2 mL dose was applied at a maximum spacing of 15 cm around the tree stem circumference. Trees with a circumference of up to 15 cm received one herbicide dose, with further doses were applied incrementally around larger trees, to a maximum of six doses.

Table 1. Herbicide treatment list for neem tree herbicide trial, Di-Bak® products are capsules, others are a liquid solution. Back transformed mortality (%) at final assessment date.

Capsule Product	**Active ingredients**	**Active rate (mg ai per cap)**	**Final mortality (%) ***
Di-Bak AM	metsulfuron methyl + aminopyralid	30+37.5	100.0[a]
Di-Bak M	metsulfuron methyl	100	99.3[a]
Di-Bak P	picloram	70	95.9[ab]
Di-Bak G	glyphosate	261	89.1[bc]
Di-Bak I	imazapyr	265	82.3[c]
Liquid product (mix rate product to water)		**mg ai per L**	
Tordon Regrowth Master (1 to 4)	triclopyr + picloram + aminopyralid	80 + 40+ 10	100.0[a]
WeedMaster Duo (1to 1)	glyphosate	360	100.0[a]
Tordon 75-D (1 to 1.5)	2,4 D + picloram	182 + 45	99.3[a]
Komachi (1 to 2.3)	aminopyralid	48	87.2[bc]
Garlon (1 to 2.3)	triclopyr	364	85.1[bc]
Access (1 to 59 diesel)	triclopyr + picloram (basal bark)		100.0[a]

*Back transformed means shown, untransformed Least Significant Difference statistic = 0.2092 and standard error of means = 0.1009. Means with the same letters are not significantly different ($p < 0.01$).

Pre-treatment trunk circumference measured near ground level and health scores were recorded on the 7/6/23, or 28/6/23 for the three additional drill and fill treatments. All plots were assessed on 4/9/23, 15/12/23, 26/4/24 and 17/11/24. Health scores from 1 (dead) to 10 (no effect) were listed by Brazier *et al.* (2024) and were recorded after inspecting each tree and inflicting small stem wounds into the wood.

Mortality per plot at the final assessment date (proportion dead, 0 to 1) was Arcsine transformed and analysed with Analysis of Variance in Genstat® v24. Final mortality for each treatment was back transformed and shown as percentage in Table 1. In treatments with <95% mortality, further analysis was conducted on the final health score and the pre-treatment circumference of the tree, or the circumference divided by the number of drill doses or capsules (cm per dose).

An additional 13 large *A. indica* trees with single trunks were treated with 1 to 4 Tordon Regrowth Master (Table 1) on 26/4/24 and assessed 7 and 15 months later. The basal circumferences ranged between 53 and 166 cm and 2 mL doses were applied at 12 to 15 cm intervals around the base of each tree.

Results

All A. *indica* trees treated with WeedMaster Duo, Tordon Regrowth Master, Di-Bak AM, and the basal bark treatment (Table 1) were controlled. The treatments with final mortalities above 95% (Table 1) are expected to be effective on *A. indica* trees up to 70 cm circumference. At the time of the final assessment all the plants in the control plots were alive.

A single live tree remained in a Di-Bak M plot and in a Tordon 75-D plot. The tree in the Tordon 75-D plot had the largest single stem circumference (77.1 cm) in the trial and was treated with six x 2 mL doses of the herbicide solution. This suggests additional or closer treatments may be needed, although a 68.5 cm circumference tree was effectively controlled with five x 2 mL doses of Tordon 75-D.

There were five trees alive in one Di-Bak P plot. The plants were of different sizes and in the last plot treated late on 8/6/23, so they may have been mistreated. With the live trees in one plot, this treatment mean was influenced (upwards) by the data transformation.

The five trees alive in Di-Bak G treated plots had circumferences over 34.9 cm, although three plants above this size were controlled. The live plants also had a ratio of more than 11.5 cm of circumference per capsule and may have been more effectively controlled with a maximum ratio of a capsule for every 10 cm of circumference. Similar results were evident across the Di-Bak I plots with a mix of live and dead trees above 23 cm circumference and above 11.4 cm of circumference per capsule. The effectiveness of the Komachi and Garlon liquid treatments were also inconsistent above drill dose ratios of one to 11 and 12 cm of circumference, respectively.

Eleven of the thirteen extra trees treated with Tordon Regrowth Master were dead 15 months after treatment. The two live plants had circumferences of 91 and 166 cm and live tissue on one side of the trunk, while another 3 trees with basal circumferences of 91, 99 and 130 cm were effectively controlled by 14 or 18 mL of this drill and fill herbicide application.

Discussion

Stem injected herbicides provided effective control of *A. indica* across a wide range of stem sizes, with several treatments achieving mortality equivalent to the reference basal bark method while using substantially less herbicide. The basal bark treatment required several litres of mixture to treat 45 trees, whereas drill and fill treatments used only 166 to 194 mL of concentrated herbicide solutions, and encapsulated Di-Bak treatments required 88 to 94 capsules for 45 trees per treatment. Stem injection techniques deliver the herbicide directly into the vascular system of the *A. indica* trees where it is retained, making the treatments suitable for using on weeds amongst desirable vegetation. This contrasts with external methods such as basal barking, where herbicide may be lost to the environment. These results demonstrate that stem injection can achieve high efficacy with markedly reduced chemical inputs, offering advantages of operational efficiency, cost reduction and environmental protection.

Several encapsulated herbicides performed well despite being applied at wider spacing intervals and lower active ingredient concentrations than than the glyphosate, imazapyr and metsulfuron capsules reported by Miller *et al.* (2019). Operators should follow the Di-Bak product labels and broader control recommendations are for treating weeds at 10 cm intervals of circumference. A reduced dose density contributed to variability in Di-Bak G, Di-Bak I, Garlon and Komachi treatments. Doses at a maximum of one per 10 cm of circumference may have led to greater mortality across these plots.

Glyphosate based herbicides will control *A. indica* and the drill and fill rate was 100% effective. The Di-Bak G in this trial was less than active rate tested by Miller *et al.* (2019), and this encapsulated herbicide also had a lower circumference threshold for effective control in an *L. leucocephala* trial (Brazier *et al.* 2024). The results from the Tordon herbicides containing picloram and the possible mistreatment of the Di-Bak P plot, show *A. indica* is also susceptible to picloram based herbicides. Tordon Regrowth Master controlled all plants up to 91 cm circumference and some up to 130 cm; larger plants may require additional treatments. Similarly, *A. indica* was effectively treated by capsules containing metsulfuron with and without aminopyralid. Further research could investigate liquid herbicide solutions containing picloram, picloram + triclopyr, dicamba, metsulfuron + aminopyralid or metsulfuron to expand the drill and fill herbicide options available for *A. indica* control.

Azadirachta indica forms a transient soil seed bank and requires 3 to 5 years to reach maturity (Brooks *et al.* 2025). With no input of fresh seeds, a short-term control programme with the effective stem injection control of mature trees and follow up control of seedlings can successfully eliminate local infestations. While long distance seed dispersal by frugivores and water (Setter *et al.* 2022) is possible, a relatively low proportion of seeds may establish (Brooks *et al*. 2025). Although though high fruit production, local seedling recruitment can be very dense and require follow-up treatments (Silayo and Kiwango 2010).

Conclusion

The high mortality of *A. indica* achieved in this study, combined with substantially reduced chemical volumes, demonstrates that stem injection of liquid and granule herbicides are a precise, low impact technique suitable for sensitive riparian and rangeland environments. Treatments were effective across a broad range of stem sizes, including trees up to approximately 130 cm circumference when the dose density is adequate. Larger stems may require additional doses or retreatment. Stem injection provides strategic advantages for rangeland management by delivering herbicide directly into the vascular system, where it is retained within the target plant.

Integrating effective stem injection treatments with systematic seedling control provides a practical and efficient pathway for localised eradication of *A. indica* in northern Australian rangelands, while minimising chemical use and environmental exposure.

Acknowledgements

The research site was identified and trial supported by staff from Whitsunday Regional Council. Dr Wayne Vogler and Melissa Setter commented on the draft paper.

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