



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)

Influence of land type on pasture productivity under variable rainfall: evidence from six SWIFTSYND sites in northern Queensland

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Key words: GRASP modelling; Grazing Land Management (GLM) land types; pasture productivity; nitrogen uptake; FORAGE

Abstract

Inter-annual rainfall variability across northern Australia presents major challenges for grazing management across landscapes characterised by diverse land types and variable pasture responses. Matching livestock numbers to available forage remains fundamental to sustainable and profitable grazing systems. The Queensland FORAGE decision-support system uses the GRASs Production (GRASP) soil-water-pasture growth model to estimate pasture production across contrasting grazing land types. This study integrated measured soil and pasture data with calibrated GRASP simulations to investigate the drivers of pasture productivity across six long-term SWIFTSYND sites representing contrasting Grazing Land Management (GLM) land types in northern Queensland, Australia. Model calibration incorporated land type-specific parameter sets implemented within FORAGE together with detailed soil, pasture and climate measurements collected between 2013 and 2021. Measured soil water holding capacity (SWHC) and maximum pasture nitrogen (N) uptake were evaluated alongside modelled pasture growth and rainfall-use efficiency (RUE). Despite a relatively narrow range in median annual rainfall (485-582 mm), median pasture growth varied markedly among land types, ranging from 1133 to 4147 kg DM ha⁻¹. Box country and Box and napunyah exhibited the lowest SWHC, N uptake and pasture productivity, whereas Loamy alluvials and Yellowjacket with other eucalypts supported greater pasture production. Although Narrow-leaved ironbark on deeper soils had the highest measured SWHC, only moderate pasture growth was simulated, indicating that soil water storage alone did not explain productivity. Yellowjacket with other eucalypts exhibited the highest pasture growth, RUE and N uptake, reflecting the combined influence of soil fertility and pasture composition. These findings demonstrate that land type mediates pasture productivity through interactions among nutrient availability, soil water storage and pasture composition rather than rainfall alone. Integrating measured soil and pasture information with GRASP simulations strengthens FORAGE outputs and supports more informed, land-type-specific grazing and stocking decisions under variable climatic conditions.

Introduction

Inter-annual rainfall variability across northern Australia presents major challenges for grazing management and long-term enterprise sustainability. Matching livestock numbers to available forage remains fundamental to maintaining productive and resilient grazing systems. However, pasture responses to rainfall vary considerably across landscapes because of differences in soil and land resource characteristics (McKeon *et al.* 2004, Stone *et al.* 2021). Although rainfall is the primary driver of pasture growth, differences in soil depth, texture, fertility and water storage among land types can produce markedly different pasture production under similar rainfall (Hall *et al.* 1998).

The GRASs Production model (GRASP Rickert *et al.* 2000) has been extensively applied throughout northern Australia to simulate pasture growth, soil water dynamics and carrying capacity under variable climatic conditions (Hall *et al.* 2001, McKeon *et al.* 2004). Within the Queensland FORAGE decision-support system, GRASP uses land type-specific parameter sets to estimate long-term pasture productivity and forage availability (Zhang *et al.* 2021). Although land type is explicitly represented within these modelling frameworks, relatively few studies have examined how measured soil resource characteristics correspond with modelled pasture productivity across representative grazing land types.

This study utilised six long-term SWIFTSYND (Philp and Day 1997) monitoring sites representing contrasting Grazing Land Management (GLM) land types in northern Queensland to examine

relationships among soil water holding capacity (SWHC), maximum pasture nitrogen (N) uptake, and modelled pasture productivity. Specifically, we evaluated the relative importance of soil water storage and plant N uptake in explaining pasture productivity among land types and the implications for interpreting GRASP/FORAGE outputs and improving land-type-specific grazing management.

Methods

The study was conducted at the Spyglass Beef Research Facility (19.49°S, 145.69°E), approximately 110 km north-west of Charters Towers, Queensland, Australia. Six long-term SWIFTSYND monitoring sites established between 2013 and 2021 represented contrasting GLM land types: Box country, Box and napunyah, Loamy alluvials, Narrow-leaved ironbark on deeper soils, Narrow-leaved ironbark on shallower soils, and Yellowjacket with other eucalypts. These land types span a wide range of soil characteristics, including shallow gravelly texture-contrast soils with restricted water storage (Box country and Box and napunyah), deep alluvial soils with relatively high plant-available water capacity (Loamy alluvials), texture-contrast soils differing in effective rooting depth (Narrow-leaved ironbark), and deep red earths (Yellowjacket).

SWHC was determined from soil cores collected at 0-10, 10-50 and 50-100 cm depth intervals. Sampling depth varied among sites because gravelly and rocky subsoils restricted coring and augering; therefore, SWHC was calculated to the maximum measured depth for each land type. Maximum plant N uptake was determined from N measured from end of wet season pasture growth measurements.

Daily climate data (1889-2025) were obtained from the SILO database (<https://www.longpaddock.qld.gov.au/silo/>) and used to derive median annual rainfall. Calibration of the SWIFTSYND site models was undertaken using CEDAR GRASP (version 2.1.02 2011) and GRASP Calibrator (version 1.33 Build 7177) software, incorporating GLM land type-specific parameter sets implemented within FORAGE together with site-specific soil, pasture and climate measurements. Rainfall use efficiency (RUE) was calculated as the ratio of median annual pasture growth to median annual rainfall. Measured SWHC, maximum N uptake, rainfall, simulated pasture growth and RUE were compared among land types using descriptive and exploratory analyses.

Results

Median annual rainfall varied only modestly among the six land types (485-582 mm), whereas measured profile SWHC ranged from 63 to 243 mm and maximum pasture N uptake from 10 to 29.9 kg N ha⁻¹ (Table 1).

Table 1. Measured soil resource characteristics and modelled productivity indicators for six SWIFTSYND land types at Spyglass Beef Research Facility

Land Type	Profile SWHC (mm)	Maximum N uptake (kg N ha ⁻¹)	Median rainfall (mm)	Median pasture growth (kg DM ha ⁻¹)	RUE (kg DM ha ⁻¹ mm ⁻¹)
Box country	80	12.7	485	1133	2.3
Box and napunyah	69*	10	551	1418	2.6
Narrow-leaved ironbark on deeper soils	243	18.6	519	1582	3.0
Narrow-leaved ironbark on shallower soils	63**	24.7	582	2595	4.5
Loamy alluvials	171	25.1	518	2650	5.1
Yellowjacket with other eucalypts	199	29.9	522	4147	7.9

*maximum measured depth 50 cm

**maximum measured depth 70 cm

Modelled median pasture growth differed markedly among land types, ranging from 1133 to 4147 kg DM ha⁻¹, while RUE varied from 2.3 to 7.9 kg DM ha⁻¹ mm⁻¹ (Table 1). The lowest pasture growth and RUE were observed in Box country and Box and napunyah, whereas Yellowjacket with other eucalypts exhibited the highest pasture growth, maximum N uptake and RUE. Loamy alluvials also supported relatively high pasture growth, whereas Narrow-leaved ironbark on deeper soils had the highest measured SWHC but only moderate pasture growth (Figure 1).

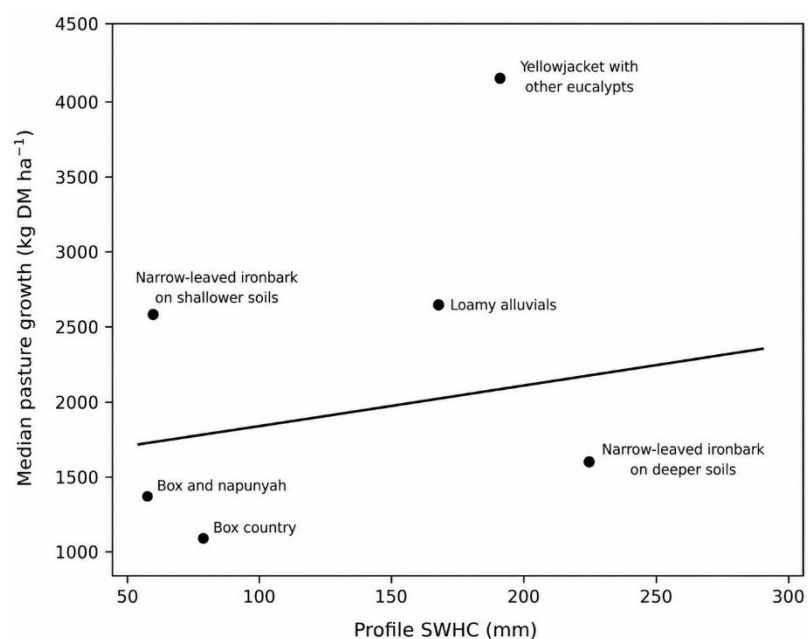


Figure 1. Relationship between measured profile soil water holding capacity (SWHC) and modelled median pasture growth across six SWIFTSYND grazing land types at Spyglass Beef Research Facility. Median pasture growth was positively correlated with maximum pasture N uptake (Pearson's $r = 0.92$; linear regression $R^2 = 0.84$, $P = 0.01$) (Figure 2). No significant correlations were observed between pasture growth and measured profile SWHC ($r = 0.36$; $R^2 = 0.13$, $P = 0.48$) or median annual rainfall ($r = 0.21$; $R^2 = 0.04$, $P = 0.70$).

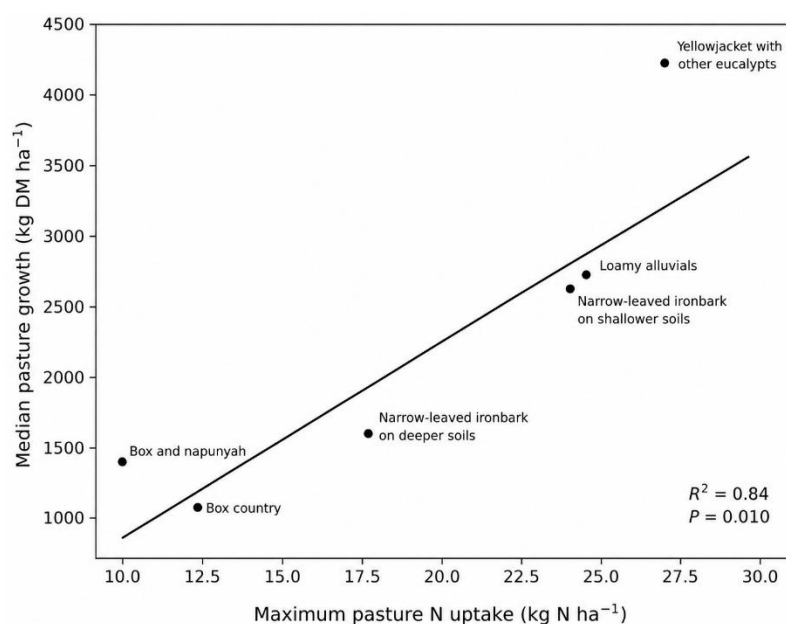


Figure 2. Relationship between maximum pasture nitrogen (N) uptake and modelled median pasture growth across six SWIFTSYND grazing land types at Spyglass Beef Research Facility

Discussion and Implications

Despite relatively similar median annual rainfall across the six land types, substantial variation in pasture productivity was observed, indicating that rainfall alone does not explain differences in productive capacity. Instead, maximum pasture N uptake showed a strong positive relationship with modelled pasture growth, whereas measured profile SWHC was not significantly correlated with pasture production. These findings suggest that, under the climatic conditions represented by the long-

term simulations, soil fertility, reflected by plant N uptake, was a stronger determinant of pasture productivity than measured soil water storage.

The low pasture growth and RUE observed in Box country and Box and napunyah are consistent with the shallow, gravelly and sodic soils characteristic of these land types, which limit nutrient availability and pasture growth (Hall *et al.* 1998). In contrast, Loamy alluvials and Yellowjacket with other eucalypts exhibited greater N uptake and pasture production. Although Narrow-leaved ironbark on deeper soils had the greatest profile SWHC, pasture productivity remained moderate, demonstrating that greater soil water storage alone does not necessarily translate into higher pasture growth. This suggests that nutrient supply and site characteristics, including vegetation composition, rooting and tree competition, may influence pasture production (Hall *et al.* 1998, McKeon *et al.* 2004).

Although Yellowjacket with other eucalypts is generally regarded as a relatively low-fertility land type, its high productivity should be interpreted cautiously. Stylo contributed up to 32% of the pasture sward and was included within the total biomass simulated by GRASP. Consequently, the relatively high N uptake and pasture production likely reflect the combined effects of legume contribution and site characteristics rather than the inherent productivity of the land type alone. In addition, the deep, well-structured red soils characteristic of this land type may have promoted greater rainfall infiltration and reduced runoff during high-intensity rainfall events, potentially increasing the amount of water available for pasture growth, although this was not evaluated in the present study.

These findings reinforce that land type influences pasture productivity through differences in soil fertility and nutrient availability, while annual rainfall primarily determines growth within each land type. Integrating measured soil and pasture information with GRASP simulations improves FORAGE outputs and provides confidence in land-type-specific stocking and grazing management decisions across variable northern Australian grazing systems (Hall *et al.* 2001, Zhang *et al.* 2021).

Acknowledgements

This research was funded through the Drought and Climate Adaptation Program (DCAP), with co-investment from the Queensland Reef Water Quality Program. The authors thank Queensland Department of Primary Industries staff at Spyglass Beef Research Facility and Charters Towers for their support with SWIFTSYND site establishment and field data collection.

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