Cambridge Prisms: Drylands

www.cambridge.org/dry

Micro catchments moderate soil surface temperatures in an arid rangeland

Rudi Swart[1], Nelmarié Saayman[1], David J. Eldridge[2] and Suzanne J. Milton[3]

[1]Plant Science, Western Cape Department of Agriculture, South Africa; [2]Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW, 2052, Australia and [3]Wolwekraal Conservation and Research Organisation, Prince Albert, South Africa

Research Article

Cite this article: Swart R, Saayman N, Eldridge DJ and Milton SJ (2026). Micro catchments moderate soil surface temperatures in an arid rangeland. *Cambridge Prisms: Drylands*, **3**, e13, 1–5
https://doi.org/10.1017/dry.2026.10028

Received: 05 December 2025
Revised: 05 March 2026
Accepted: 20 March 2026

Keywords:
rangeland restoration; soil temperature; microclimate; soil pits; furrows

Corresponding author:
David J. Eldridge;
Email: d.eldridge@unsw.edu.au

Abstract

Arid rangelands can be highly productive, but are often degraded by human activity, particularly soil disturbance due to mining, overgrazing or unsustainable farming practices. A range of soil treatments is used to rehabilitate and restore degraded rangelands. These focus on the capture of water and wind-blown sediment to promote vegetation growth and soil stabilisation. We examined how moderately large human-constructed micro catchments altered soil surface temperatures in a pilot trial to explore their potential impacts on vegetation establishment. We found that temperatures at the base of the depressions (pits) were greater than those in the controls in both summer and winter, but only in the mornings. Under high daytime temperatures, however, the pits were always cooler than the controls. This moderating effect on surface temperatures likely provides a more suitable environment for plant establishment and growth.

Impact statement

Drylands are an important global land type that support millions of people, yet large areas are currently degraded. We show how artificially constructed micro catchments in an arid rangeland have a moderating effect on soil surface temperature, reducing it under hot conditions but increasing it when temperatures are low. This moderating effect could have a substantial positive effect on plant growth and, therefore, make micro depressions a relatively inexpensive technique to restore arid rangelands.

Introduction

Drylands are critically important globally, covering about 40% of the terrestrial land area (Cherlet et al., 2018) and supporting a similar percentage of the global population. Drylands also support most of the world's livestock and are critically important for providing a substantial range of ecosystem goods and services such as climate regulation, water supply and other contributions to people (Eldridge et al., 2024). Yet drylands are also subject to extreme degradation caused by resource overexploitation, overgrazing and unsustainable farming practices that reduce forage production, weaken ecosystem functions and accelerate erosion and the loss of critical resources. Restoration can reverse or alleviate degradation, but is often time-consuming, expensive and is reliant on suitable climatic conditions (Snyman, 1999; Saayman et al., 2017).

Mechanical soil surface treatments such as ploughing, ripping, discing, pitting and the creation of hollows, semi-circular bunds and micro catchments have been used globally to restore degraded rangelands (Gintzburger and Skinner, 1985; Whisenant, 1999). These techniques all share a unifying principle: the creation of a depression that traps runoff and sediment, reduces the erosive power of water and promotes the establishment of self-sustaining vegetation (Bothma and van Rooyen, 2006; Mganga et al., 2022; Eldridge and Ding, 2023; Johnston and Mann, 2024). Mechanical treatments range from large ponding banks that can occupy many hectares (Rhodes, 1987) to small pits and furrows that have a short lifespan (Eldridge and Ding, 2023). When combined with mulching, reseeding and grazing exclusion, these structures can accelerate ecosystem recovery (Bothma and van Rooyen, 2006). The optimal type of structure, however, depends on soil texture, slope, rainfall regime and the availability of labour and mechanised equipment.

Rangelands in various stages of degradation cover about half of the world's land area and 70% of South Africa's land area (Hoffman et al., 1999). In the arid Karoo region of South Africa, micro catchments of different sizes have shown promise for promoting the establishment of perennial shrubs and grasses (Snyman, 2003; Milton and Coetzee, 2022), but their effectiveness is thought to depend on their size. Field experience indicates that shallow, circular micro catchments of about 1 m in diameter and 20 cm in depth are effective traps for sediment and water without excessive siltation. Anecdotal evidence suggests that larger structures can flood or smother seedlings under deposited sediment. Smaller structures tend to fill rapidly with silt and become less effective (Coetzee, 2005; Eldridge and Ding, 2023). In a small-scale restoration trial at the

© The Author(s), 2026. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

Wolwekraal Nature Reserve near Prince Albert, South Africa, hand-dug, seeded and mulched micro catchments promoted vegetation recovery, even under prolonged drought conditions (Milton and Coetzee, 2022). Minimal runoff and the absence of runoff suggest that factors other than surface water capture, possibly modified soil microclimate conditions, contributed to their success. The extent of any potential moderating effect of micro catchments on surface temperatures is not well understood. Temperature is important because it controls the effects of soil biota on plant growth (Heinze et al., 2017). Restoration interventions that buffer soil surface temperatures and reduce evaporation may therefore play a valuable role in improving plant establishment in a restoration environment (Esler et al., 2006).

We used a field-based study to examine changes in temperature in moderately sized human-constructed micro catchments in arid rangelands in South Africa. Our aim was to compare temperatures at three microsites (base of the depression, hereafter 'pit', rim of soil surrounding the micro catchment, hereafter 'mound', control surface, 'control') across two seasons (summer, winter) and diurnal periods (morning, afternoon). The effect of restoration structures on temperature is important because it gives us insights into the potential for these human-constructed structures to support vegetation and therefore to restore degraded rangelands.

Methods

Study area

The study was conducted at three arid to semi-arid sites in the Western Cape Province of South Africa: Worcester Veld Reserve, Wolwekraal Nature Reserve near Prince Albert and Nortier Research Farm near Lambert's Bay on the west coast. The Worcester and Nortier sites experience a Mediterranean climate, with mean annual rainfall of 257 mm and 197 mm respectively, while Prince Albert has an arid climate with mean annual rainfall of 175 mm (Western Cape Department of Agriculture, 2025).

The Worcester and Prince Albert sites are underlain by shallow, poorly developed soils dominated by the Mispah and Glenrosa soil forms. These soils are typically shallow, rocky and high in clay content. In contrast, the Nortier site consists of fine aeolian sands of the Namib soil form (Western Cape Department of Agriculture, 2025). At the Prince Albert site, January is the warmest month with a mean temperature of 22.2 °C, while February is the warmest month at Worcester (22.3 °C) and Nortier (19.7 °C) (Western Cape Department of Agriculture, 2025). July is the coldest month at all sites, with average temperatures of 10.8 °C, 11.0 °C and 12.9 °C for Prince Albert, Worcester and Nortier, respectively.

Experimental design and analyses

At each of the three sites, we constructed 20 micro catchments on a 5 x 4 grid, with individuals placed about 10 m apart. Each micro catchment was about 1 m in diameter with a concave base approximately 20 cm deep at the centre (Figure 1). Micro catchments were dug by hand, and the excavated soil heaped on the downslope side to form a small mound to retain any runoff water (Coetzee, 2005).

We used a hand-held infrared thermometer to measure soil surface temperature in three microsites: 1) at the bottom of the pit, 2) on the top of the mound, and 3) a level site within 30 cm of the micro catchment ('control'). Measurements were taken at dawn

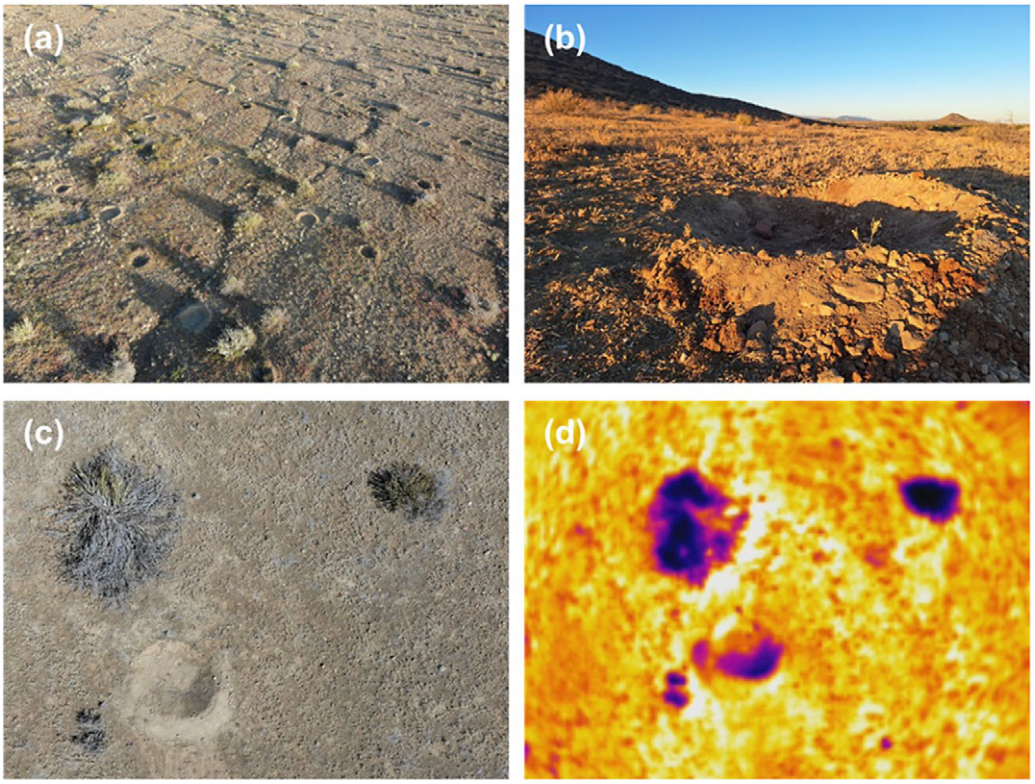


Figure 1. Images of the micro depressions and surrounding area. (a) aerial view of micro depressions showing the 5 x 4 arrangement with depressions at 10 m spacings, (b) individual pit and mound, (c) drone image of a pit/mound complex and the surrounding control area taken at 14:00 at the Prince Albert site, and (d) same drone image taken with a Forward Looking Infrared (FLIR) camera showing the lower temperature in the pit microsites of the depressions and in the shrub hummock than the surrounding control surface. Darker colours correspond to lower temperature. Images taken in Austral summer (February 28, 2024).

https://doi.org/10.1017/dry.2026.10028 Published online by Cambridge University Press

(06:00 in summer, 07:00 in winter) and at 14:00 (timing) during both summer and winter (season) to represent the coolest and warmest periods of the day and over the year. At all sites, we measured temperatures in the austral summer (late February-early March) and winter (late July–early August) as close as possible to avoid confounding weather conditions. Observations were restricted to days with minimal cloud cover and low wind speeds to reduce variation in soil temperatures. Two measurements were made of each combination of site x microsite x season x timing, and the mean value was used in the analyses. Thus, for the analysis, we had a total of 720 observations (20 measurements each of 3 microsites × 2 seasons × 3 sites × 2 times).

We used a mixed-models (*syn.* split-plot) approach using the package lme4 to examine the effect of Season, Timing, Microsite and their two-and three-way interactions on surface temperatures. The model had three residual terms. The first stratum considers Season, Timing and its interaction and the second stratum Microsite, and its two-and three-way interactions with Season and Timing. The third stratum was solely a residual (error) term that accounted for the variation among the 20 micro catchments at each site in relation to all four factors. The emmeans package in R (Lenth and Piaskowski, 2025) was used to estimate the marginal means for different groups and to compare and contrast the levels of Microsite, Season and Timing. Model diagnostics using the plot() command in R revealed no evidence of overdispersion, zero-inflation or deviation from uniformity, and no influential outliers were detected.

Results

We found considerable variation in temperature across seasons and time of day, particularly in winter mornings on both mounds and controls (Table 1). Morning temperatures were predictably lower than those in the afternoon. Importantly, however, we found a significant three-way interaction among Microsite (pit, mound, control), Season (winter, summer) and Timing (morning, afternoon; $F_{1,16} = 4.06$, $P = 0.037$). The three-way interaction indicated that temperatures at the base of the micro catchments were always greater than those in the controls in both summer and winter, but only in the morning when temperatures were relatively low (13-15 °C). In the afternoons, however, when diurnal temperatures ranged from about 24 to 51 °C, temperatures were lower in the base of the micro catchments (pits) in summer, but higher in the pits in winter. The greatest temperature difference was in summer in the afternoon (Table 2). There were no differences in temperature between the mounds created from spoil during pit excavation and the control surfaces, except in the afternoon in summer ($P = 0.019$), when mound temperatures were identical to those in the base of the micro catchments (Figure 2).

Table 1. Mean and coefficient of variation (CV%) in temperature (°C) in relation to microsite, season and time of day

Microsite	Season	Timing	Mean	CV%
Pit	Summer	Afternoon	48.4	8.99
Pit	Summer	Morning	15.1	17.72
Pit	Winter	Afternoon	25.3	22.12
Pit	Winter	Morning	3.4	44.71
Mound	Summer	Afternoon	48.3	12.71
Mound	Summer	Morning	12.8	12.90
Mound	Winter	Afternoon	25.4	25.87
Mound	Winter	Morning	1.1	223.13
Control	Summer	Afternoon	50.8	10.37
Control	Summer	Morning	13.3	14.60
Control	Winter	Afternoon	24.0	20.36
Control	Winter	Morning	1.0	96.50

Table 2. Summary of differences in temperature between pit and control surfaces

Period	Temperature difference	Temperature trend	*P*-value
Winter – Morning	1.48	Pit > Control	0.0110
Winter – Afternoon	1.28	Pit > Control	0.0276
Summer – Morning	1.73	Pit > Control	0.0030
Summer – Afternoon	2.35	Pit < Control	0.0001

Discussion

Our study demonstrates that artificially constructed micro catchments moderate soil surface temperatures compared with both control areas and the accretion mounds constructed from excavated material. Specifically, mounds reduced soil surface temperature during hotter periods but had the opposite effect when the ambient temperatures were cooler. The narrowing of the temperature range within the micro catchments likely provides a more suitable microclimate for seed germination and seedling establishment (Esler et al., 2006; Milton and Coetzee, 2022) and will likely contribute to vegetation establishment and survival.

Soil surface temperature is a major driver of ecosystem functions in drylands and has flow-on effects to a number of soil and ecological processes (Heinze et al., 2017). For example, lower summer afternoon temperatures in the micro catchments likely increase opportunities for plant growth and survival because of greater soil moisture due to reduced surface evaporation (Zhuo et al., 2017). Temperature changes in the pits and mounds could be due to differences in soil moisture, which is known to affect ambient temperature close to the surface (Alexander, 2011). Higher soil temperature in the matrix between

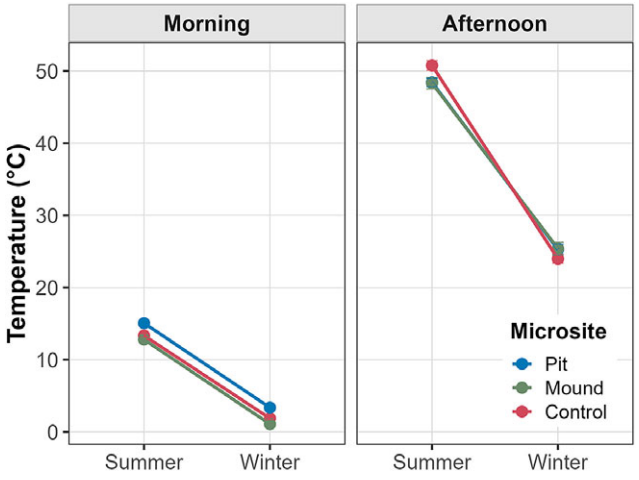


Figure 2. Mean (± SE) morning and afternoon soil surface temperatures (°C) in summer and winter for pits, mounds and adjacent controls.

https://doi.org/10.1017/dry.2026.10028 Published online by Cambridge University Press

micro catchments is likely indicative of a lower content of soil carbon, given the strong links between temperature and soil moisture, and therefore organic matter (Hartley et al., 2021). Higher surface temperature and greater solar radiation promote abiotic breakdown of organic matter, and a loss of carbon to the atmosphere rather than its sequestration into the soil organic pool (Austin and Vivanco, 2006). The potential loss of soil organic matter can lead to an increased risk of erosion, and therefore reductions in soil productive potential (Sarah, 2006). Yet, by moderating soil surface temperatures, micro catchments can initiate feedback processes whereby there are further reductions in surface temperature as plants colonise the treated areas and the plant canopy helps to trap rainfall (O'Brien and Hatfield, 2019). Increased plant growth in the micro catchments would be expected to ameliorate temperatures even more strongly, particularly when those plants are woody perennials. For example, temperatures have been shown to be lower beneath woody canopies in summer, but higher in winter under dryland conditions in the Iberian Peninsula (Lozano-Parra et al., 2018). These predicted effects, although intuitive, would need to be tested by further empirically-based studies in micro catchments.

Soils that are more prone to large fluctuations in temperature may benefit less from restoration techniques such as pitting, furrowing and micro catchments if soil temperature amelioration is the restoration goal. Fine-textured soils have greater thermal conductivity than coarse-textured soils due to their finer pore structure and tendency to retain water much longer than coarser soils. Thus, the construction of micro catchments is likely to be more effective on finer-textured soils such as clays or silts (Akter et al., 2015). Micro catchments have other advantages that relate more to the capture and storage of water in drylands. For example, small pits and furrows are commonly used in deserts and rangelands to trap water and support plant growth (Gintzburger and Skinner, 1985; Friedel et al., 1996; Jahantigh and Pessarakli, 2009; Strohmeier et al., 2021). Many of these structures are very small and therefore have a short longevity. Pits created by the Tyne pitter (Eldridge and Ding, 2023) rapidly fill with sand and fail to act as sinks for water. Micro catchments in the current study, however, are relatively large and capture a large volume of water ($\sim 0.1\ m^3$), so are likely to persist over long time periods.

Unlike machine-made structures, our micro catchments are relatively cheap to construct and require little regular maintenance. They are likely to be more practical in areas where machinery is unavailable, could damage remaining vegetation or is prohibitively expensive. Furthermore, we maintain that additional ecosystem benefits can result from the addition of mulch and brush material in the micro catchments (brush packing, Mangani et al., 2022). This is likely to reduce wind chill, trap moisture and further enhance the prospects for vegetation establishment (Mangani et al., 2022). For example, Neilly et al. (2025) showed that placing woody debris on the soil surface increased plant cover and richness, and reptile abundance on eroded soils. Micro catchments may have an effect on the formation of dew, a critical water source in deserts (Yu et al., 2020). The micro catchment walls may experience greater dew deposition due to their height and size, thereby advantaging plants close to the edge of the depression.

Finally, our measurements were made when wind speeds were low, thereby removing anomalous temperatures lower than would be expected for a given season or time of day. Temperatures were measured under low wind speed conditions to reduce any confounding effects across microsites, seasons and times. Under high wind speed conditions, temperatures would likely be lower in the control sites, but this would need to be tested experimentally. Further, temperature was only measured in two seasons and at two times of the year, so more information would be needed to fully appreciate the extent of temperature change over an entire season and year to realise the potential effects of temperature on the restoration of degraded soils.

Ongoing studies have yet to determine the effects of micro catchments on plant germination and survival. Nonetheless, our results show that they provide warmer temperatures in winter, which would create microsites more conducive to plant growth. Notwithstanding these results, further studies are needed to understand the interactions between soil type and temperature, to investigate the depths over which temperature moderation occurs, and to document soil moisture responses to temperature differences in and out of micro catchments and the likely impacts of mulching and brush addition on plant establishment and survival.

Open peer review. For open peer review materials, please visit http://doi.org/10.1017/dry.2026.10028.

Data availability statement. The data are currently part of an ongoing project and will be uploaded to a relevant data repository on project finalisation.

Acknowledgements. This project was supported by the Western Cape Department of Agriculture, and the Wolwekraal Nature Reserve. We thank Dr Eve Slavich for statistical advice.

Author contribution. Rudi Swart: Writing – Conception, original draft preparation, review and editing. Nelmarié Saayman: review and editing. David Eldridge: analysis, review and editing, Sue Milton: review and editing.

Competing interests. The authors declare no competing interest.

References

Akter M, Miah MA, Hassan MM, Mobin MN and Baten MA (2015) Textural influence on surface and subsurface soil temperatures under various conditions. *Journal of Environmental Science and Natural Resources* **8**, 149–159.

Alexander L (2011) Climate science: Extreme heat rooted in dry soils. *Nature Geoscience* **4**, 12–13.

Austin AT and Vivanco L (2006) Plant litter decomposition in a semi-arid ecosystem controlled by photodegradation. *Nature* **442**, 555–558.

Bothma JP and Van Rooyen N (2006) Veld and soil reclamation. In Bothma JP (ed.), *Game Ranch Management*. Pretoria: Van Schaik Publishers, pp. 638.

Cherlet M, Hutchinson C, Reynolds J, Sommer S, Von Maltitz G (2018) *World Atlas of Desertification*. Publication Office of the European Union.

Coetzee K (2005) *Caring for Natural Rangelands*. Scottsville: University of KwaZulu-Natal Press.

Eldridge DJ and Ding J (2023) Pitting fails to sustain increases in ecosystem structure in arid rangelands. *Restoration Ecology* **31**, e13929.

Eldridge DJ, Wang C, Liu Y, Ding J, Li Y, Wu X and Li C (2024) Nature's contribution to people in drylands. *Cambridge Prisms: Drylands* **1**, e2. https://doi.org/10.1017/dry.2024.2.

Esler KJ, Milton SJ and Dean WRJ (2006) *Karoo Veld Ecology and Management*. Pretoria: Briza.

Friedel MH, Kinloch JE and Müller WJ (1996) The potential of some mechanical treatments for rehabilitating arid rangelands. I: Within-site effects and economic returns. *The Rangelands Journal* **18**, 150–164.

Gintzburger GA and Skinner PW (1985) A simple single disc pitting and seeding machine for arid rangeland revegetation. *The Australian Rangeland Journal* **7**, 29–51.

Hartley IP, Hill TC, Chadburn SE and Hugelius G (2021) Temperature effects on carbon storage are controlled by soil stabilisation capacities. *Nature Communications* **12**, 6713. https://doi.org/10.1038/s41467-021-27101-1.

Heinze J, Gensch S, Weber E and Joshi J (2017) Soil temperature modifies effects of soil biota on plant growth. *Journal of Plant Ecology* **10**, 808–821.

Hoffman MT, Todd S, Ntoshona Z and Turner S (1999) *Land Degradation in South Africa*. Cape Town: National Botanical Institute.

Jahantigh M and Pessarakli M (2009) Utilization of contour furrow and pitting techniques on desert rangelands: Evaluation of runoff, sediment, soil water

content and vegetation cover. *Journal of Food, Agriculture and Environment* **7**, 736–739.

Johnston DB and Mann RK (2024) Rangeland pitting for revegetation and annual weed control. *Rangelands* **46**, 23–30.

Lenth R and Piaskowski J (2025) emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 2.0.0. Available at https://CRAN.R-project.org/package=emmeans (accessed 5 February 2026).

Lozano-Parra J, **Pulido M**, **Lozano-Fondón C and Schnabel S** (2018) How do soil moisture and vegetation covers influence soil temperature in drylands of Mediterranean regions? *Water* **10**, 1747. https://doi.org/10.3390/w10121747.

Mangani T, **Mangani R**, **Chirima G**, **Khomo L and Truter W** (2022) Using mulching to reduce soil surface temperature to facilitate grass production. *Heliyon* **8**, e12284.

Mganga KZ, **Bosma L**, **Amollo KO**, **Kloko T**, **Kadenyi N**, **Ndathi AJN**, **Wambua SN**, **Kalndi EM**, **Musyoki GK**, **Musimba NKR and van Steenbergen F** (2022) Combining rainwater harvesting and grass reseeding to revegetate denuded African semi-arid landscapes. *Anthropocene Science* **1**, 80–90.

Milton SJ and Coetzee K (2022) Hollows bring new life to bare patches in Karoo even in drought. *Grassroots* **22**, 11–14.

Neilly H, **Cale P and O'Sullivan J** (2025) Branching" with woody debris as a multipurpose restoration tool in an overgrazed arid landscape. *Restoration Ecology* **33**, e14363.

O'Brien PL and Hatfield JL (2019) Extreme soil surface temperatures reflect need to rethink agronomic management. *Agricultural Environmental Letters* **5**, e20002. https://doi.org/10.1002/ael2.20002.

Rhodes DW (1987) Waterponding banks: Design, layout and construction. *Journal of the Soil Conservation Service of NSW* **43**, 80–83.

Saayman N, **Cupido C**, **Botha H and Swart R** (2017) Possible rehabilitation methods of *Galenia africana*-dominated old lands in the Cederberg Mountains, South Africa. *African Journal of Range and Forage Science* **34**, 167–171.

Sarah P (2006) Soil organic matter and land degradation in semi-arid area. *Israel. Catena* **67**, 50–55.

Snyman HA (1999) Soil erosion and conservation. In Tainton N (ed), *Veld Management in South Africa*. Pietermaritzburg: University of Natal Press, p. 376.

Snyman HA (2003) Revegetation of bare patches in a semi-arid rangeland of South Africa: An evaluation of various techniques. *Journal of Arid Environments* **55**, 417–432.

Strohmeier S, **Fukai S**, **Haddad M**, **Ainsour M**, **Mudabber M**, **Akimoto K**, **Yamamoto S**, **Evett S and Oweis T** (2021) Rehabilitation of degraded rangelands in Jordan: The effects of mechanized micro water harvesting on hill-slope scale soil water and vegetation dynamics. *Journal of Arid Environments* **185**, 104338.

Western Cape Department of Agriculture (2025) CapeFarmMapper. Available at https://gis.elsenburg.com/apps/cfm/.

Whisenant SG (1999) *Repairing Damaged Wildlands: A Process Oriented, Landscape-Scale Approach*. Cambridge: Cambridge University Press.

Yu R, **Zhang Z**, **Lu X**, **Chang I-S and Liu T** (2020) Variations in dew moisture regimes in desert ecosystems and their influencing factors. *WIREs Water* **7**, e1482.

Zhuo L, **Han D and Dai Q** (2017) Exploration of empirical relationship between surface soil temperature and surface soil moisture over two catchments of contrasting climates and land covers. *Arab Journal of Geoscience* **10**, 410. https://doi.org/10.1007/s12517-017-3183-x.

https://doi.org/10.1017/dry.2026.10028 Published online by Cambridge University Press