DINTERIA No. 31: 38-49 – Windhoek, Namibia – 2009/2010

The effects of "pebble mulch" on *Acacia mellifera* seedling responses to rain

David. F. Joubert

School of Natural Resources and Tourism
Polytechnic of Namibia
Private Bag 13388, Windhoek, Namibia
E-mail: djoubert@polytechnic.edu.na
Telephone: ++264 61 2072462
Fax: ++264 61 2072143

Abstract

"Pebble mulch" (a layer of quartz and schist pebbles that often forms an almost 100 % cover on the slopes of the Highland Savannah in Namibia) influences the dynamics of this vegetation type. A controlled experiment to determine the effects of "pebble mulch" on seed germination and early seedling establishment of *Acacia mellifera* (subsp. *detinens*) was conducted. *A. mellifera* forms dense thickets in the area. Seeds were germinated under four treatments: **A**: planted below soil (2 seed widths depth) without pebble cover; **B**: planted below soil (2 seed widths depth) *with* pebble cover. **C**: planted on top of soil underneath a 100 % pebble cover and **D**: planted on top of a 100 % pebble cover. Emergence/germination and seedling survival and vigour were recorded regularly for five weeks. Emergence/germination in all cases was high (overall 82 % s.d. 17.5 %). Soil moisture was significantly higher in all "pebble-mulch" treatments (B, C and D). Although initial establishment was poor in Treatment D (33 %), survival thereafter of seedlings whose radicles reached the soil was very high (97 %). Seedling survival and vigour were significantly higher in all "pebble-mulch" treatments. The implications of these results for bush encroachment on Highland Savanna rangelands are discussed.

Key words

Bush encroachment; seedling; pebble mulch; Highland Savannah; *Acacia mellifera* subsp. *detinens*.

Introduction

Bush encroachment may be regarded as the densification and increase in cover of bush at the expense of grass production that affects savannahs and other vegetation types throughout the world (e.g. Hodgkinson & Harrington, 1985; Archer *et al.,* 1988). These include savannas in southern African countries such as Botswana, South Africa (e.g. Donaldson, 1967; Trollope *et al.*, 1989; Skarpe, 1990; Roques *et al.*, 2001; Moleele *et al.*, 2002;) and Namibia (Bester, 1999). Bush encroachment affects approximately 26 000 000 hectares of Namibian semi-arid rangeland (De Klerk, 2004). As early as the 1960s, bush encroachment was seen as a major economic problem in Namibia (Bester, 1996). It is estimated that N$ 700 000 are lost in reduced beef production per annum (De Klerk, 2004) and this figure is likely to have doubled by 2009.

It is widely accepted that bush encroachment in southern Africa was initiated largely by the introduction of large herds of domestic ungulates in the 19th century through colonial expansion (Walker *et al.*, 1981). At the same time grazing patterns had been changed through the establishment of permanent water points, which limits the mortality of livestock in non-nomadic rangeland management (Skarpe, 1992). Bush encroachment then occurs when bush seedlings and established bushes obtain a competitive advantage over grasses for soil moisture (Walter, 1971; Knoop & Walker, 1985), facilitated by excessive grazing. However, grass is likely to be more important as a fuel for fire, which kills the seedlings (Joubert *et al.*, 2008). Prior to colonial occupation, there were already landscape scale areas of bush encroachment in Namibia. Andersson (1856) gives no less than five accounts of hardship, including lacerated cattle and torn clothes from thorns as he trekked through bush encroached areas in his explorations through Namibia in the early 1850s. These landscape scale bush encroached areas appear to have been near permanent water. Game, and later livestock herds of nomadic pastoralists who had become partially sedentary, would have concentrated in these areas, reducing grass biomass to such an extent that periodic fires were impossible. In more recent years, fires were deliberately excluded, for economic reasons, particularly since the 1950s (De Klerk, 2004).

Despite the long interest and concern in bush encroachment, there is little consensus today on the major causes. Recent work focuses on the stochastic nature of establishment associated with successive good rainfall periods and the absence of fire (Joubert *et al.*, 2008) and the cyclical nature of bush thicket and open savannah succession (Meyer *et al.*, 2007).

Various authors have investigated microsite effects on seedling survival of woody species in rangelands. For example, Harrington (1991) noted that herbaceous cover negatively affected seedling establishment of *Dodonaea attenuata* in Australian rangelands. In South Africa, Smith and Shackleton (1988) suggested that *Acacia tortilis* seedlings have a lower survival rate in the shade of parent trees, but O’Connor (1995) noted that *Acacia karroo* seedlings survival was improved by grass shading of seedlings, presumably due to improved moisture availability. He attributed this to the effect of shade on moisture availability. In Kwa-Zulu Natal, South Africa, Walters *et al.*, (2004) found that *Dichrostachys cinerea* seeds did not germinate in the field after fire and that burning of *A. karroo*, *Acacia nilotica* and *Acacia luederitzii* seeds did not affect germination. All of the above mentioned species have been identified as problem species implicated in bush encroachment.

No work on microsite effects on seed germination and seedling establishment of bush encroaching species in Namibia has been done, except for a current study which is investigating the effects of parent trees on seedling survival of *A. mellifera* (Joubert, 2007). Kraaij & Ward (2006) concluded that grass competition was generally not a factor in semi-arid rangelands.

Study Area

The Highland Savannah Vegetation Biome of central Namibia (Fig. 1) (Giess, 1971) is a semi-arid Savannah biome characterised by a mean annual rainfall of approximately 360 mm (CV = 39.6 %) in Windhoek (Namibia Meteorological Services). There is a gradient of decreasing mean annual rainfall from east to west. Most rain falls within the months of October to April.

Figure 1: The Highland Savannah biome (shaded area) of Namibia (from Giess, 1971).

In summer, maximum temperatures are lower than would be expected for an area just north of the Tropic of Capricorn, due to the area’s elevation, while winters are very cold (minimum temperatures of -7ºC are recorded occasionally) and frost occurs frequently (Mendelsohn *et al.,* 2002). The terrain is broken and undulating, at altitudes ranging from 1 350 to 2 400 m above sea level and with slopes exceeding 30º in places. The steep slopes are covered by a shallow lithic leptosol (Mendelsohn *et al.*, 2002) typically only 30 cm in depth and with a high gravel content, largely comprising of schist and quartz.

Although bush encroachment in the Highland Savannah is less of a problem than in the Thornbush Savannah just north of the Highland Savannah (Giess, 1971) where rainfall is higher and soils are deeper, *Acacia mellifera* subsp. *detinens*, the main encroaching species, can reach densities of over 15 000 individuals per hectare (Joubert, 2007). In the Highland Savannah, bush encroachment primarily seems to affect footslopes (Fig. 2). The steep slopes of the Highland Savannah are characterised by a covering of mostly rounded quartz pebbles (resulting from prior erosion). This cover of pebbles often approaches 100 % (Fig. 3) but is less on footslopes than steeper midslopes (Joubert, 1997). This almost continuous layer affords significant protection from evaporation, functioning in a similar way to litter mulch.

Figure 2: Typical Highland Savannah slope on farm Krumhuk near Windhoek. Note that bush encroachment only occurs on the footslope.

In view of this function the layer may therefore be considered as "pebble mulch". It might be expected that the pebble mulch prevents seeds from contacting the soil, and would thus reduce germination success. However, observations in the field in January 2001 showed that many seeds of *A. mellifera* had germinated on top of the pebble mulch, after the exceptionally high rainfall of 1999/2000 (more than double the long term mean annual rainfall). These seedlings died prematurely, with the radicles barely emerging more than a few millimetres from the testa. In these cases, the radicles were too short to reach the soil surface below before they dried up, owing to a lack of follow up rain or insufficient energy reserves. There is not likely to be much seed burial by rodents and insects under a pebble-mulch, since the pebble cover is so extensive, and well embedded in the loamy sand soil. Where the roots of seedling do reach and penetrate the soil it would be expected that the stone cover improves the chances of survival and establishment through its mulching effect, and protection of the soils from rain-splash impact. Normally, steep stony mid-slopes in the Highland Savannah are characterised by being in better veld condition than less stony footslopes, with a much better cover of climax or decreaser perennial grasses (Joubert, 1997).

Seed supply from mature fruiting *A. mellifera* trees is intermittent and rare in the Highland Savannah and is strongly correlated with rainfall (both for seed production and seedling establishment) (Joubert *et al*., 2008). Seed banks are thus ephemeral (Joubert, 2007; Bester

Figure 3: A typical "pebble mulch" cover in the Highland Savannah. In this photograph, there is almost 100 % cover of the soil by mainly quartz pebbles.

pers. comm.). The exceptionally high rainfall in 1999-2000 initiated significant production of seeds, while the following year’s high and well-spaced rainfall allowed for good seedling survival (Joubert, 2007).

This paper reports on the results of a study of seed germination/emergence and seedling survival under controlled conditions to address the following questions: Will pebble mulch inhibit initial seedling establishment if seeds germinate on the surface? Will pebble mulch enhance the survival and vigour of seedlings when compared with no stone cover?

Materials and Methods

Eight seeds were planted in each of 12 trays of 8 cm depth for each of the following planting treatments:

A. 3 mm (two seed widths) below the soil surface, without pebble cover.
B. Two seed widths below the soil surface, with 100 % pebble cover.
C. On the soil surface, with 100 % pebble cover.
D. On top of 100 % pebble covering the soil.

Soil (loamy sand which is typical from the Highland Savannah slopes) was obtained from Krumhuk farm 30 km south of Windhoek, where *A. mellifera* dominates, and this was chemically analysed (Table 1). All treatments used the same soil, which was free of any seeds prior to the trial. Supplementary watering was provided. This allowed soil moisture comparisons to be made between treatments. Only one supplementary watering of the equivalent of 5 mm of rain was added before germination occurred. A total of the equivalent of 250 mm of rainfall was received by each treatment during the experiment, including supplementary watering.

Soil moisture was determined using a simple gardening soil moisture testing meter with additional gradation to refine the accuracy of reading, just before supplementary watering (the meter was unitless but allowed comparisons to be made). This provided some indication of the maximum water stress that seedlings in different treatments were subjected to. Seedling survival and vigour (measured as the number of leaves per seedling) was determined five times during the course of the trial (7, 12, 15, 28 and 34 days after resuming), which ran from 30 March to 4 May, 2001).

A one-way ANOVA (StatSoft, 1999) was conducted to determine whether significant differences in soil moisture levels, germination/emergence, seedling survival and vigour (the number of leaves per seedling) occurred between treatments. Subsequently, *post hoc* comparisons were made using the LSD (Least Squares Difference) test to determine which treatments significantly differed in each measurement (soil moisture levels, germination, seedling survival and vigour). In all cases data were close to normally distributed.

Results

The experiment simulated fairly extreme conditions, since seedling trays would have experienced higher evaporation and drainage rates than the situation in the field.

Overall germination/emergence was very high (82 % ± 17.5 %). This is to be expected since *A. mellifera* seeds have a thin testa and do not rely on passage through the alimentary canal of an ungulate to break dormancy. In fact, the great majority of seeds ingested by ungulates are destroyed in the gut. Only 3 % of seeds ingested by steers germinated in laboratory conditions (Donaldson, 1967).

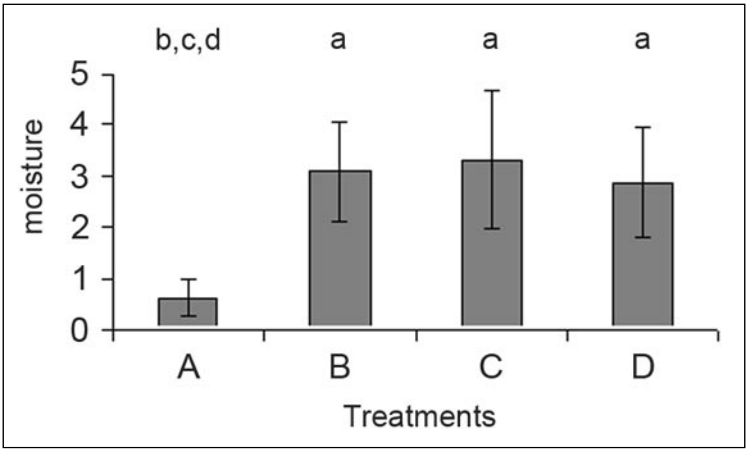

Figure 4: Soil moisture as measured with a soil moisture test kit. Actual soil moisture is not measured. The numbers provide a relative measure. Letters denote significant differences ($p < 0.05$ – LSD post hoc comparison test). Bars denote standard deviations. N = 12 for each treatment.

Although treatments where seeds were placed above ground showed a slightly (but significantly) higher germination/emergence success (Figure 5), germination rates of treatments A and B may have been underestimated since the germination process underground could not be observed, and some germinated seeds may have died from fungal infections before emerging. Most seeds germinated/emerged within seven days of planting.

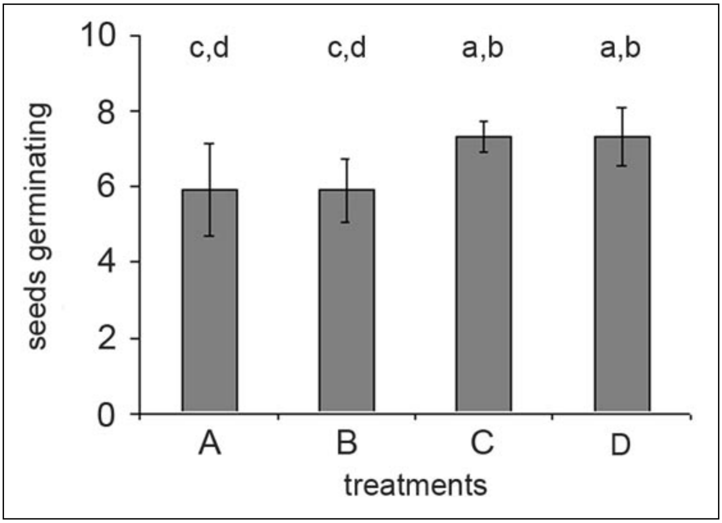

Figure 5: Mean germination per seed tray of A. mellifera in the four different treatments:
Letters denote a significant difference ($p < 0.05$, LSD post hoc comparison test). Bars denote standard deviations. N = 12 for each treatment.

Seedling survival in the initial stages was low in treatment D (33 %), as seedling radicles were exposed to the air and easily desiccated. Observations in the field indicate that a small radicle normally emerges after germination before seedlings die due to exposure to air and insufficient moisture. Once the radicles had grown and entered the soil however, seedling survival was high (97 % of the remaining seedlings survived) (Figure 6). Pebble mulch treatments overall showed significantly better survival rates than Treatment A (no "pebble mulch"). Treatment A showed very low survival rates overall (Figure 7).

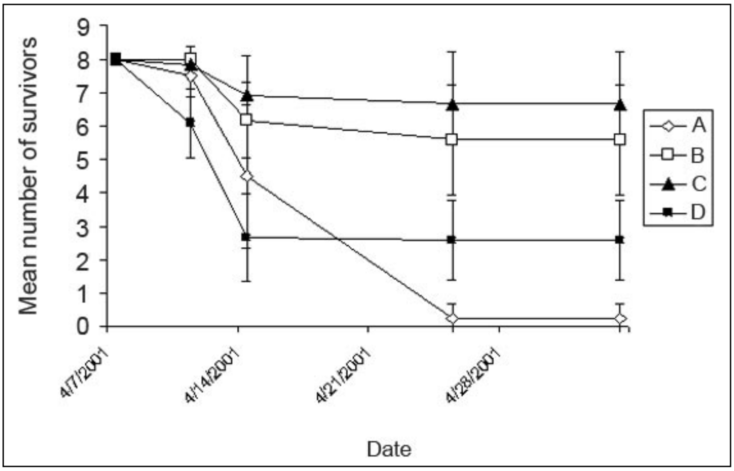

Figure 6: Seedling survival throughout the trial for the different treatments (error bars denote standard deviations). N = 12 for each treatment.

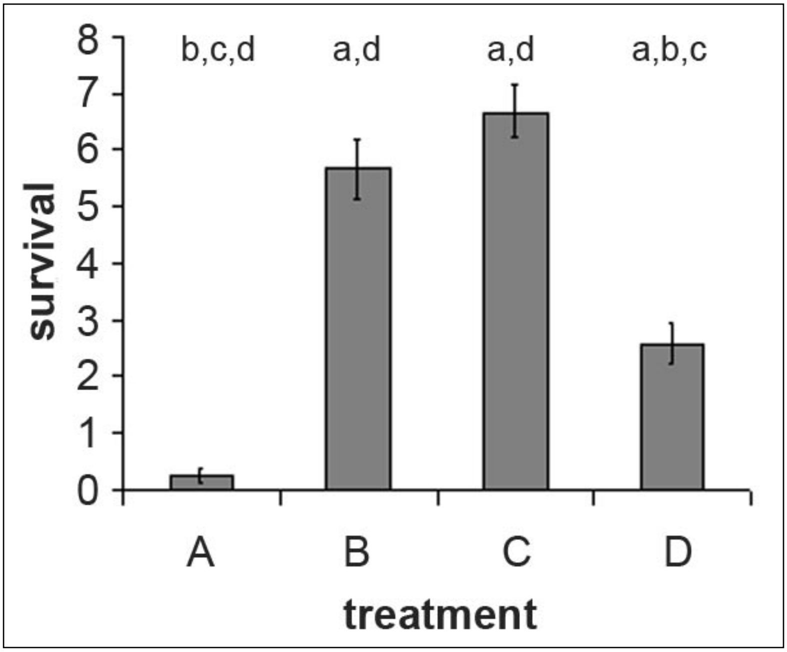

Figure 7: Overall seedling survival at the end of the trial (from 8 seeds in each tray). Letters denote significant differences between treatments ($p < 0.05$, LSD post hoc comparison test). Bars denote standard deviations. N = 12 for each treatment.

The vigour of seedlings in all "pebble mulch" treatments is significantly higher than for without "pebble mulch" (Figure 8). It is unlikely that the seedlings surviving Treatment A would have survived a dry winter, as they were spindly and lacked woody development and thorns.

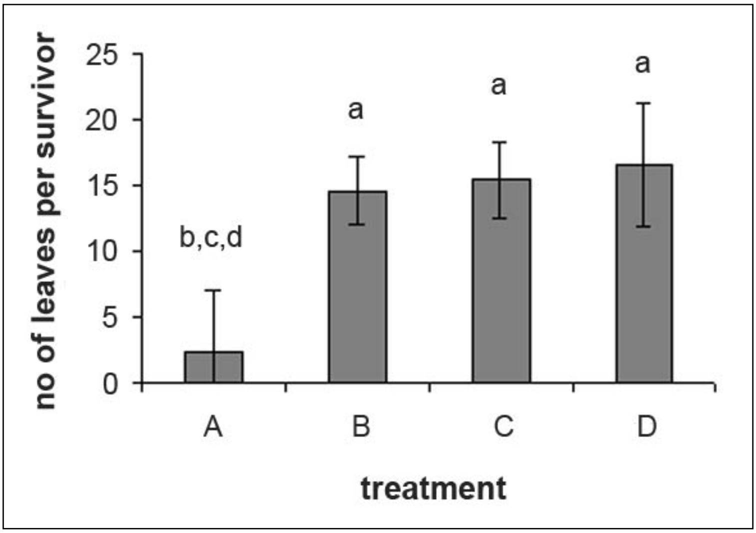

Figure 8: Vigour (as expressed as number of leaves per survivor). Letters denote significant differences between treatments ($p < 0.05$; LSD post hoc comparison test). N = 12 for each treatment c,d

Discussion

A. mellifera only produces large amounts of seeds in good rainfall years, as occurred in 1999-2000 (Joubert *et al*, 2008). *A. mellifera* does not depend on dispersal by ungulates since ungulate alimentary tracts are likely to destroy the seeds, which are thin and have a thin testa (Donaldson, 1967), unlike other *Acacia* species, including *A. erioloba*, which has a thicker, harder testa. In *A. erioloba* and other *Acacia* species with indehiscent pods, the passage through an ungulate's alimentary canal favours germination (Hoffmann *et al*., 1989; Barnes, 2001; Miller, 1994). In the field, very few seedlings of *A. mellifera* are found far from parent trees. If rainfall is poor following seed set, very few or no seeds are likely to remain in the seed bank, since germination occurs easily (Figure 5) but seedlings do not receive sufficient rain to survive. In poor rainfall years then, the seed bank is likely to be eliminated by germination with 100 % mortality of seedlings. This is supported by Donaldson's (1967) observations in the Molopo region in South Africa and Bester's (*pers. comm.*) in Namibia, as well as Joubert's unpublished field data. In good rainfall years (in the 2000-2001 season, rainfall was above average and well spaced), establishment may be very high, particularly if microsites are favourable. This would depend upon seed production in the previous year. In 1999-2000 very high seed production was observed in the field in the Highland Savannah, whereas in the previous three seasons at least, no seed production occurred in monitored plots (Joubert, 2007.). At least two consecutive favourable rainfall years seem to be necessary for the establishment of seedlings (Joubert *et al*., 2008).

Initially, the pebble mulch acted as an impediment to seedling establishment. However, surviving seedlings whose radicles managed to penetrate the soil surface showed very high survival after establishment. Seedlings in soils without pebble cover showed almost no survival by the end of the experiment due to the almost negligible residual soil moisture prior to rain events and supplementary watering. Seedlings under pebble cover showed much higher vigour, due to the greatly improved soil moisture conditions. These seedlings showed signs of secondary growth and are thus much more likely to be able to survive winter frosts than the rather spindly seedlings surviving with no pebble mulch. Although pebble cover initially inhibits seedling establishment, the density of seedlings managing to establish is sufficiently high to negate the initial inhibition, and in fact promote establishment.

Stone or pebble cover is important for improving soil moisture conditions in the Highland Savannah and probably has a profound influence on vegetation structure. On typical steep slopes, where pebble cover is generally high, there is usually a greater cover of decreaser perennial grasses than on footslopes with little pebble cover (Joubert, 1997), partially as a result of improved soil moisture conditions, as well as less utilisation by ungulates. In such cases the positive effect of pebble cover on *A. mellifera* seedling establishment is countered by the greater competition with grasses for moisture, increased likelihood of fires, and the fact that dispersal up slope is probably very limited. However, in areas where this grass cover is removed (as through overgrazing), *A. mellifera* seedlings may survive and establish in rainfall conditions lower than what might be expected. This means that *A. mellifera* thickets may creep up slope, which currently is not normally the case. The observation that bush encroachment is currently generally restricted to foot slopes in the Highland Savannah partially reflects the greater seed banks present on foot slopes owing to water movements, and the presence of more parent trees. However, gradual upslope seed dispersal cannot be discounted. Continuous grazing on steep pebbly mid slopes after exceptional rainfall may initiate a bush encroachment event and change the pattern of encroachment in the Highland Savanna from being mainly restricted to footslopes to occurring more generally on steeper midslopes and upper slopes.

In determining models for seedling survival in relation to rainfall, the microsite effects of pebble mulch and landscape effects must be considered.

Conclusions

Rangeland managers need to take microsite effects on vegetation dynamics into account. Excessive grazing on steep pebbly slopes may initiate bush encroachment events where they are not normally observed. This may significantly increase the extent of bush encroachment on rangelands with negative effects on rangeland production and biodiversity.

Acknowledgements

I am indebted to the following:

The Polytechnic of Namibia who provided financial assistance.

My sons, Christopher and Luke, who helped with watering of seedlings as well as recording of data.

Patrick Graz who generated Figure 1 for me.

Patrick Graz and Ibo Zimmermann who commented on an earlier draft.

Axel Rothauge, who provided useful comments on the experimental design.

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