Evaluation of Restoration Techniques for the Succulent Karoo, South Africa

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Abstract

Possible constraints on the passive recovery of bare areas in the Karoo, a semiarid region in South Africa, include inadequate supply of seed, availability of suitable microsites for plant establishment, altered soil properties, and the truncation of key soil biotic processes. Here we investigate the possibility of initiating the restoration of bare areas by soil surface treatments with gypsum ($CaSO_4$) and/or organic mulch. We also apply an exogenous seed source to test the hypothesis that seed availability limits autogenic recovery. Both gypsum and mulch improved rain water infiltration, gypsum more so than mulch, and both treatments resulted in significantly higher numbers of reseeded seedlings compared with controls. Gypsum also improved the survival of the cohorts of seedlings of the larger seeded *Tripteris sinuata*. *Tripteris* showed the highest number of seedlings (maximum count of 150 seedlings/1,000 viable seeds sown) and surviving plants of the three reseeded species, which included two small-seeded species, *Ruschia spinosa* and *Chaetobromus dregeanus*. Throughout the study period significantly higher plant volumes of naturally seeded annuals and perennials were recorded in the gypsum and/or mulch treatments compared with the controls. Germination and emergence of reseeded and naturally seeded plants appears to be determined by the availability of cool season (autumn to spring) soil moisture, whereas follow-up rainfall during this time is important for plant survival. Mulching of bare areas in the Succulent Karoo has the potential to re-create vegetated areas that will further capture and conserve water, soil, and nutrients. Gypsum also showed positive results but might not be a cost-effective option because of transport costs to these remote arid areas.

Key words: bare areas, gypsum, infiltration, organic mulch, reseeding, restoration, South Africa, Succulent Karoo.

Introduction

The degradation of arid and semiarid rangelands is a worldwide phenomenon (Call & Roundy 1991; Milton & Dean 1995; Ludwig & Tongway 1996). Degradation is generally evident in a decline in productivity at all spatial scales and has a direct bearing on the capacity of the rangeland to support grazing animals and to provide a sustainable income to the landowner. One model, which attempts to conceptualize this degradation process, was presented by Westoby et al. (1989). In this state-and-transition model of vegetation change there is a set of discrete states of vegetation and a set of discrete transitions between states, rather than a steady vegetation change along a single continuum. It follows that to reverse degradation it may be necessary to force the system to jump or cross a threshold from one stable state to another (Hobbs & Norton 1996). Management input may be required to reduce the leaking of resources (soil, water, nutrients) (Whisenant & Tongway 1996), restore propagule pools (Milton 1994), and es-

tablish the belowground components of the ecosystem, including a healthy soil microbial community (Whitford et al. 1988; Zink & Allen 1998).

Milton et al. (1994) developed a state-and-transition model for the Karoo, a semiarid region in South Africa, that invokes stepwise degradation, starting with plant demographic changes, followed by plant and animal losses, and eventually major changes in soil condition and processes. According to the model, grazing animals and their hooves alter the outcome of competitive interactions among plants, differentially influence the reproductive output of forage and nonforage species, and influence microsite availability for seedling establishment (Milton & Hoffman 1994). Milton and Hoffman (1994) further argue that there are important interactions between climatic factors and transition processes that need to be understood for successful restoration of karoo rangelands. The challenge is to reverse or alter the course of this stepwise degradation process, bearing in mind that the more degraded the land, the greater the management and costs required to return the system to previous states (Milton et al. 1994; Hobbs & Norton 1996).

The Ceres Karoo (also known as the Tanqua Karoo) is part of southern Africa's winter-rainfall succulent karoo biome (Milton et al. 1997). The region has been subjected to occasional but heavy grazing bouts in winter by nomadic pastoralists for at least 2,000 years (Rubin 1998). Large herds of *Antidorcas marsupialis* (Springbok) migrated from

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the summer-rainfall Nama Karoo to the east into the Ceres Karoo during the winter months when food was relatively abundant (Skinner 1993). These pulsed grazing events probably had limited impact on the vegetation and soils of the region. Degradation and accelerated soil erosion were initiated by heavy continuous grazing when graziers permanently occupied the region since the late nineteenth century (Rubin 1998). Today much of the Ceres Karoo is in a seriously degraded state (Mackay & Zietsman 1996). Stokes (1994) postulated that much of this vegetation change has occurred since the 1940s, but since 1971, after the introduction of a stock withdrawal program, no further degradation trends were evident. The plant communities dominated by ephemerals and plants of low forage value are in a stable state, with no or very little recovery even with rests of up to 50 years (Stokes 1994).

Possible constraints on the passive recovery of bare areas and poor rangeland in the Karoo include inadequate supply of seed, availability of suitable microsites for plant establishment, altered soil properties, and the truncation of key soil biotic processes (Milton & Hoffman 1994; Stokes 1994). Here we investigate the possibility of initiating the restoration of bare areas by soil surface treatments with gypsum and/or organic mulch. We also apply an exogenous seed source to test the hypothesis that seed availability limits autogenic recovery (Whisenant & Tongway 1996). Gypsum improves the hydraulic conductivity of the topsoil when the soil is structurally degraded, for example, by sodicity (Ilyas et al. 1993), whereas mulching improves infiltration (Ludwig & Tongway 1996) and the frequency of favorable microsites (Abusuwar 1995; Milton 1995).

Study Area

Research was undertaken on the farm "Rietfontein" (4,074 ha, 32°52′S/19°54′E), situated 90 km northeast of the town of Ceres in the Ceres Karoo (Fig. 1). The land consists of a gentle slope with fanning erosion rills from about 570 m al-

titude in the southeastern boundary to about 530 m in the northwest. Run-off water is channeled along these erosion rills ("washes") to the ephemeral Ongeluks River to the north of the farm. The rock types comprise tillites (Dwyka Formation) and shales and sandstones (Ecca Formation) of the Karoo System. Geomorphologically, erosion is the dominant force in the landscape; hence, soils are young and skeletal (Ellis & Lambrechts 1986). Soils have a relatively low clay content (14% in the topsoil), are lime rich and alkaline (pH 8.0), and have a low electrical conductivity (45.8 mS/m as determined in a saturated paste) and high sodium content (exchangeable sodium percent = 3–4%). The process of clay illuviation and mechanical impact of raindrops often leads to crusting and low infiltration rates (Ellis & Lambrechts 1986).

According to Schulze (1997) the mean annual rainfall for the study area is between 100 and 200 mm, the coefficient of variation of annual rainfall is between 35 and 40%, and the mean annual A-pan equivalent potential evapotranspiration is 2,400 to 2,600 mm. A mean rainfall of 139 mm/yr was recorded on Rietfontein for the period 1995 to 1998. Most rain is recorded in the winter months (May–August) when precipitation is derived from relatively predictable westward-moving low pressure cells or cold fronts (Desmet & Cowling 1999). Warm-season rainfall is unpredictable and is associated with west coast troughs, thunderstorms, and the autumnal northerly flow of moist tropical air (Desmet & Cowling 1999). Summers are relatively hot, with average maximum temperatures greater than 30°C from December to February. The coincidence of high temperatures and low rainfall over this period results in extreme moisture stress for shallow-rooted plants. The summer aridity also results in lack of summer forage for livestock and the low carrying capacity (8 ha/sheep) of these pastures. In some places it is still a common practice for pastoralists to stock their holdings in the Ceres Karoo only for 4 to 5 months during the winter (Rubin 1998).

The vegetation of the study area is classified by Acocks (1975) as Veld Type 31 (Succulent Karoo) and by Low and Rebelo (1996) as Lowland Succulent Karoo. It is a low succulent shrubland, dominated by dwarf leaf-succulent members of the Mesembryanthemaceae, especially species of *Ruschia*, *Drosanthemum*, *Malephora*, and *Delosperma*. Annuals and geophytes may be common after good rains, but perennial grasses are scarce. The dominant plant community in the vicinity of the restoration trials for this study corresponds to the *Zygophyllum microcarpum–Lycium cinereum* open plains community described by Rubin (1998) for Tankwa Karoo National Park, 50 km north of the study area.

A perennial spring in the center of Rietfontein provides water to both humans and livestock. The water flows from cracks in the rocky bed of one of the washes and accumulates in a pool of approximately 200 m². Water can be pumped to five paddocks on a rotational basis. There were no livestock present during the study period because the farm was totally destocked in the early 1990s.

Figure 1. The study area with an experimental plot in the foreground (Photo PCB).

Methods

In April 1994 four unvegetated bare areas were identified within 400 m of the perennial Rietfontein spring, an area that had been subjected to heavy continuous grazing for many decades (Fig. 1). The bare areas selected were subjectively assessed as similar in size (approximately 0.1 ha), slope (<5%), soil surface condition (bleached A horizon), gravel cover (>80%), and surrounding plant community (*Prenia tetragona* [Mesembryanthemaceae] dominated). A 10 × 10–m plot, subdivided into eight blocks (5 × 2.5 m), was demarcated on each bare area, and in a randomized design a zero, gypsum, mulch, reseeding, gypsum-plus-mulch, gypsum-plus-reseeding, mulch-plus-reseeding, or gypsum-plus-mulch-plus-reseeding treatment was allocated to each block. The corners of the blocks were clearly marked with steel pegs, and furrows (approximately 7 cm deep) were dug around the blocks to reduce the fluvial movement of gypsum across the blocks. An equivalent of 5 t/ha gypsum ($CaSO_4$) was hand strewn onto designated blocks and lightly raked into the topsoil to reduce wind dispersion. All remaining blocks were subsequently lightly raked to avoid bias. In the blocks designated for reseeding, three lines 600 mm apart were marked with steel pegs and furrowed to approximately 10 mm depth. Approximately 2,000 seeds of *Ruschia spinosa* L. (Dehn) (approximately 50% viable) were hand sown along one furrow, 1,800 *Chaetobromus dregeanus* Nees seeds (approximately 50% viable) along another, and 600 *Tripteris sinuata* DC seeds (approximately 33% viable) along the third furrow. The furrows were closed and lightly compacted by hand. Seed viability was assessed in replicated germination experiments under nursery conditions.

These three species were chosen in an attempt to rebuild a productive community from an agricultural perspective. *Ruschia spinosa* (hereafter *Ruschia*) is a pioneer mound-forming shrub that can establish in the open (Yeaton & Esler 1990); *Tripteris sinuata* (hereafter *Tripteris*) is a winged-seeded, wind-dispersed, and highly palatable species favoring more sheltered microsites (Milton 1995); and *Chaetobromus dregeanus* (hereafter *Chaetobromus*) is a palatable perennial grass that was thought once to be more common in the Ceres Karoo (B. Bayer 1994, Dept. Agriculture, personal communication). An organic mulch in the form of thatching reed (Restionaceae), derived from discarded roofing material, was spread onto designated blocks. *Acacia karroo* branches were stacked on top of the reeds to minimize relocation by wind. Thatch was used as mulch because it grows in fynbos vegetation associated with more mesic and infertile conditions than the study site and is unlikely to contain any seeds that might confound the results of the experiment. The 10 × 10–m plots were fenced with a 60 cm high mesh wire to exclude steenbok, tortoises, hares, and rodents.

In June 1994, 3 months after the treatments and the morning after a 6-mm rainfall event, infiltration depth was determined in each block. Five vertical soil profiles per block were dug and the depth of water infiltration visually assessed by looking at soil color. The difference between moist and dry soil was easily observed, and the depth of infiltration could be measured to the nearest millimeter.

The monitoring of seedling abundance started in October 1994 and continued with at least one visit per year until a final assessment in December 1998. During each visit the abundance of live seedlings and established plants was determined. All seedlings and established plants in the marked lines were attributed to the exogenic seed source and were counted. After a severe drought in 1995, when most seedlings succumbed, reseeding of similar volumes of seed along the same lines was repeated in April 1996.

Also during each visit the seedling and/or established plant volume originating from the endogenic seed source was subjectively assessed and scored for each block. In assessing the plant volume per block, the horizontal and vertical projections of the phytomass were considered. Blocks were scored for phytomass volume on an eight-point scale where the block per plot with the largest volume received a score of eight. No attempt was made to assess the species composition of the seedling cohorts, but casual observations were made on dominant ephemeral and perennial plant species, size and vigor of plants, endogenic seed abundance and distributions, and invertebrate activities.

The highest seedling and surviving plant counts were recorded in April 1995, October 1996, and June 1997. The count data for these three survey dates were square root transformed, and the effects of gypsum and mulch were analyzed by means of parametric two-way analyses of variance. The plant volume scores for each survey date were subjected to nonparametric Kruskal-Wallis analyses of variance by ranks to determine treatment effects.

Results

The deepest rainwater infiltration occurred in the gypsum treatments ($p < 0.001$), although mulching also improved infiltration significantly ($p < 0.05$) and showed a significant interaction with gypsum ($p < 0.05$) (Table 1).

No seedlings of *Ruschia*, *Chaetobromus*, or *Tripteris* were observed in October 1994 after a very dry winter. After good rains in March 1995 (40 mm) (Fig. 2a) seedlings of all three reseeded species emerged in the following month (April) (Fig. 2 b–d). Of the three reseeded species,

Table 1. Infiltration depth (mm) after a 6-mm rainfall event on bare soils under different treatments ($n = 40$).

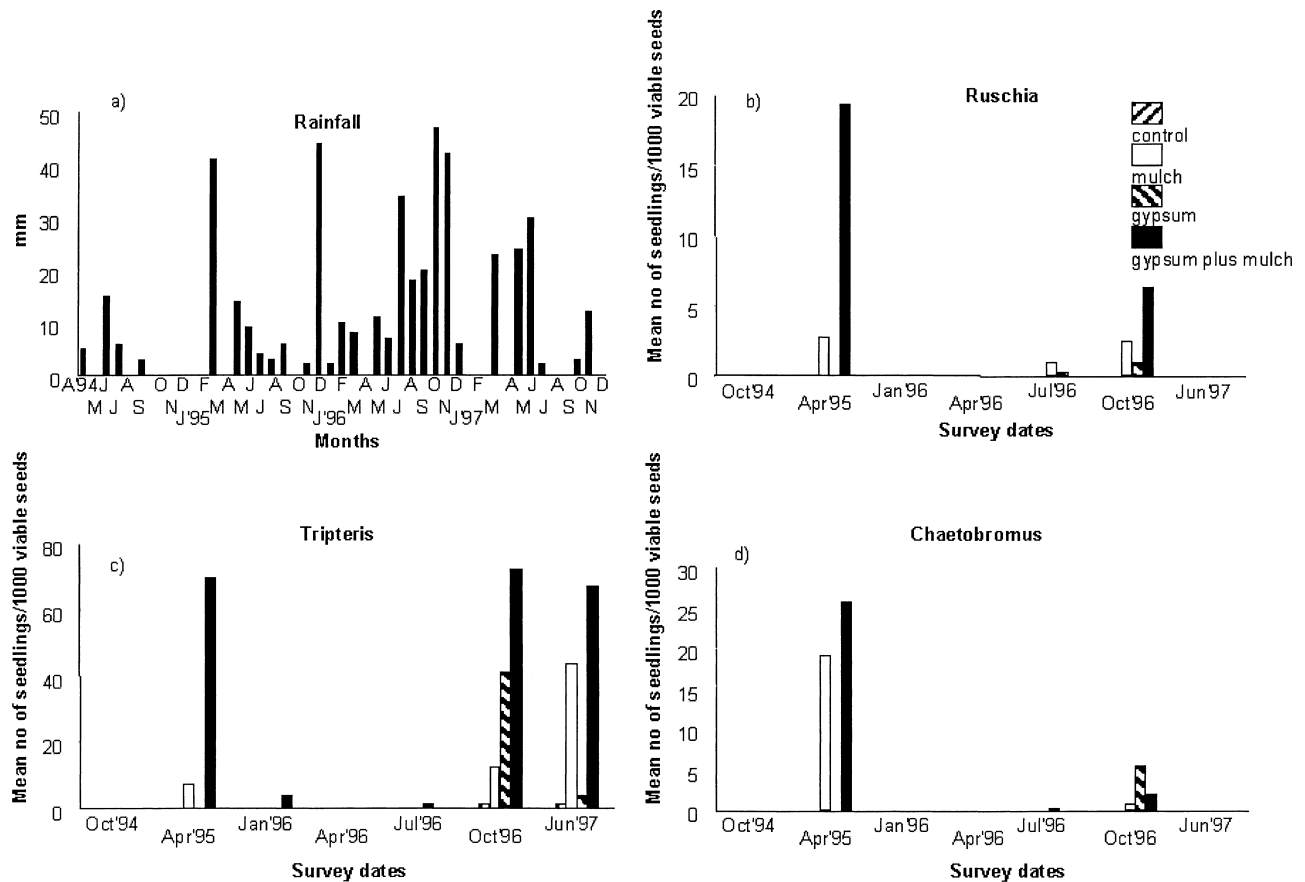| Treatment	Mean	SE	F	Significance Level
Control	34.6	2.4		
Mulch	46.8	3.6	6.5	0.0117
Gypsum	53.4	2.1	25.5	0.000
Mulch + gypsum	54.8	2.3	4.1 (interaction)	0.0440

Figure 2. Mean number of seedlings counted for three reseeded species in different treatments. Monthly rainfall is also shown.

the highest number of seedlings per 1,000 viable seeds sown was observed for *Tripteris*. For all three species the highest number of seedlings were observed in the gypsum-plus-mulch treatment (Fig. 2). Mulching and, in the case of *Tripteris*, gypsum treatment resulted in significantly higher numbers of seedlings compared with controls (Table 2). The winter of 1995 was very dry, and most establishing seedlings had perished by the following summer. The good summer rains in December 1995 (45 mm) resulted in very little establishment because few were counted in January and April 1996. Reseeding in April 1996 was followed by good winter rains. Despite this, few seedlings had emerged in mid-winter (July 1996), but a relatively good emergence was recorded in spring (October 1996), especially for *Tripteris* (Fig. 2). For both *Ruschia* and *Tripteris* significantly more seedlings were counted in blocks where the soil was treated with either gypsum or mulch or a combination of the two (Fig. 2, Table 2). For the rest of the study period no seedlings of the two small-seeded species, *Ruschia* and *Chaetobromus*, were observed. The

Table 2. Results of two-way analyses of variance of seedling counts of three species reseeded under two treatments.

Survey Date	Species	Mulch		Gypsum		Interaction	
		F *Value*	p *Value*	F *Value*	p *Value*	F *Value*	p *Value*
April 1995	*Ruschia*	10.0	0.008*	2.69	0.127	2.69	0.127
April 1995	*Chaetobromus*	17.19	0.001*	0.97	0.344	0.97	0.344
April 1995	*Tripteris*	21.05	<0.001*	7.74	0.017*	7.74	0.017*
October 1996	*Ruschia*	8.63	0.012*	1.76	0.21	0.12	0.74
October 1996	*Chaetobromus*	0.1	0.752	1.25	0.285	0.37	0.554
October 1996	*Tripteris*	3.79	0.075	11.93	0.005*	0.07	0.79
June 1997	*Tripteris*	6.62	0.024*	0.48	0.504	0.23	0.64

Count data were square root transformed.
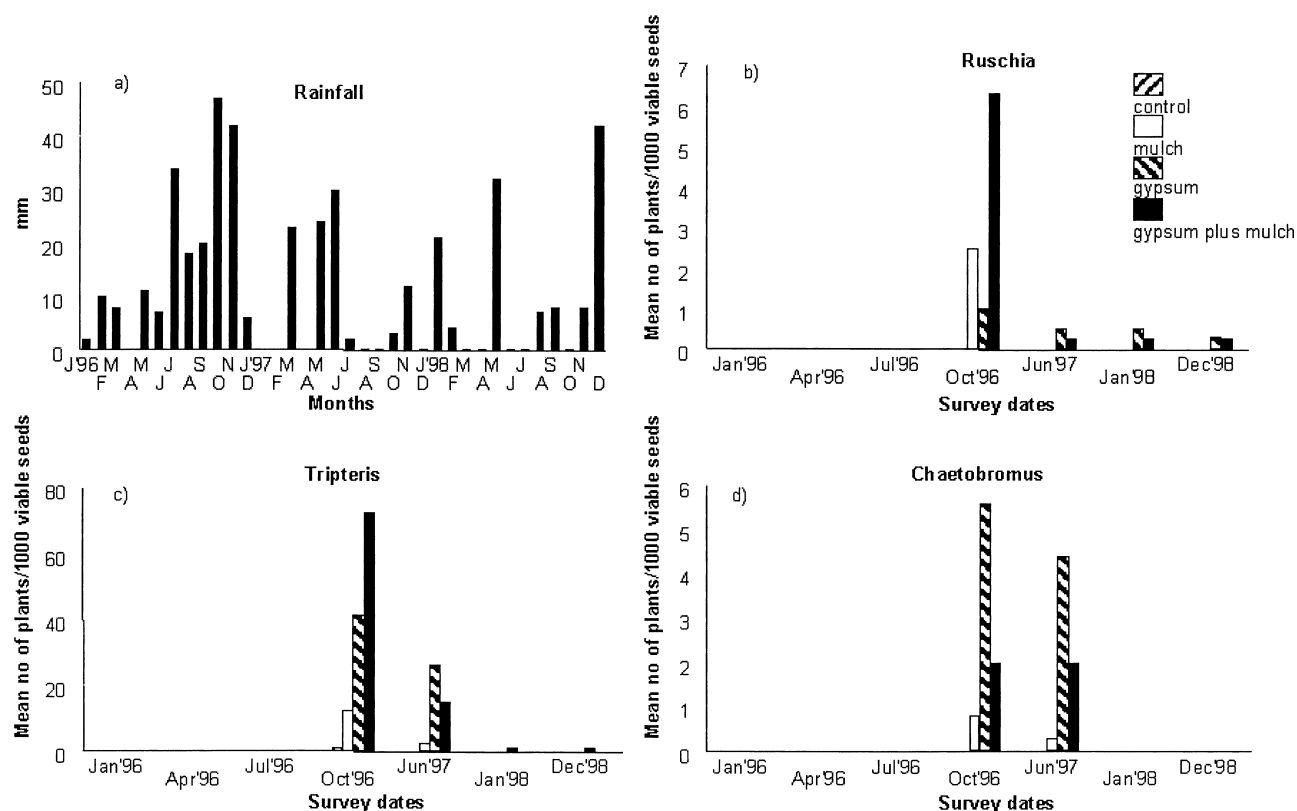* Significant at $p < 0.05$.

Figure 3. Mean number of surviving plants counted for three reseeded species in different treatments. Monthly rainfall is also shown.

larger seeded *Tripteris* showed another good germination and emergence event in late autumn and early winter (June 1997) (Fig. 2). During this time the highest seedling abundance was recorded in the gypsum-plus-mulch treatment. However, the gypsum treatment did not differ significantly from the control (Table 2).

The survival of the cohorts of seedlings that emerged from October 1996 was monitored until the end of the study period (Fig. 3 b–d). With good rains in autumn 1997 (40–50 mm) (Fig. 3a) some plants survived until the June 1997 survey. Thereafter the highly irregular winter rainfall of 1997 and 1998 resulted in the death of most plants, except a few *Ruschia* (3) and *Tripteris* (2) individuals. Although the mulch-alone treatment, or in combination with gypsum, often showed more emerging seedlings, survival was not as high as in the gypsum-only treatment (Fig. 3).

However, the effect of gypsum on survival was only significant for *Tripteris* (Table 3). In June 1997, 85 *Tripteris* plants and 18 *Chaetobromus* individuals were encountered in the gypsum-treated block with the highest counts.

Gypsum and/or mulching resulted in significantly greater endogenic seedling and established plant volume scores for most of the survey dates (Fig. 4). Plant deaths in some of the blocks toward the end of the study period caused greater variability in the scores. Therefore, nonsignificant treatment effects were recorded for the last two survey dates. Throughout the study period, the highest plant volumes occurred in the gypsum-plus-mulch treatment. There were no consistent differences between plant volumes of the gypsum-alone and mulch-alone treatments, although both treatments showed higher plant volumes compared with the control blocks (Fig. 4).

Table 3. Results of two-way analyses of variance of surviving plant counts of two species reseeded under two treatments.

Species	Mulch		Gypsum		Interaction	
	F *Value*	p *Value*	F *Value*	p *Value*	F *Value*	p *Value*
Chaetobromus	0.14	0.712	2.48	0.141	0.0	0.983
Tripteris	0.01	0.912	5.0	0.045	0.53	0.482

Counts were conducted in June 1997 and data were square root transformed. Insufficient numbers of *Ruschia* individuals were available for statistical analysis.
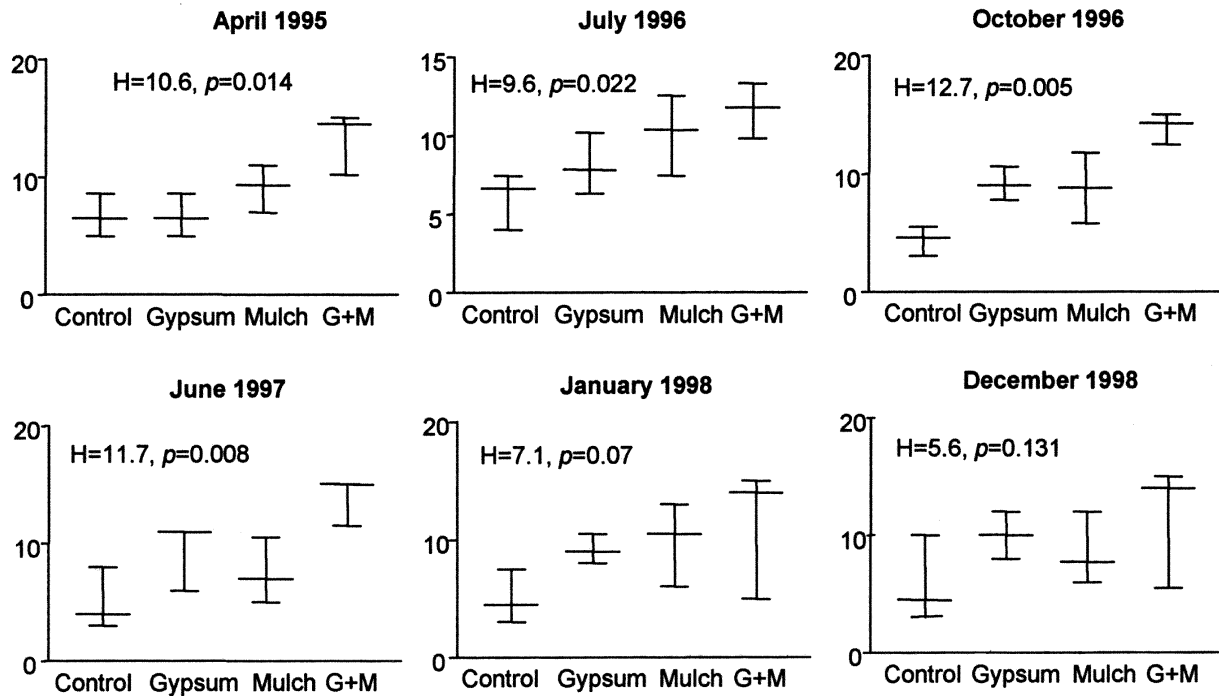
Figure 4. Box-and-whisker plots of plant volume scores for different treatments of bare areas. Results of Kruskal-Wallis analysis of variance by ranks are also given.

Discussion

The existence of extensive bare areas in close proximity to the central watering point on the farm Rietfontein can be attributed to the impacts of long-term overuse by livestock. The reduced plant cover exposed the topsoil to the mechanical dispersive effects of raindrops. The resultant crust formation was probably further aggravated by chemical dispersion, which is possible when soils are characterized by relatively high exchangeable sodium levels (3–4%) and low electrolyte concentrations (45.8 mS/m) (Du Plessis & Shainberg 1985). This crusting resulted in poor infiltration and therefore soil water conditions under which few or no perennial plants could establish and survive (Greene & Tongway 1989; Ilyas et al. 1993).

Although mulching significantly increased the depth of water infiltration into these bare area soils by probably reducing raindrop impact and ponding run-off water, chemical sealing remained a problem. This is confirmed by the fact that the infiltration depth into the gypsum-treated soils was significantly higher than in the mulch treatment. Gypsum is a slow-dissolving salt that readily contributes Ca-electrolytes to the solution, which can displace some of the exchangeable sodium adsorbed to the clay colloids and add to the electrolyte concentration (Du Plessis & Shainberg 1985). Our results support the findings of Loveday (1976) and Du Plessis and Shainberg (1985) that gypsum, applied at a rate of 5 t/ha, can provide substantial improvement in infiltration. It is expected that permanent amelioration of soil surface conditions of these bare areas will only be achieved with repeated gypsum treatments at the

above rate (Loveday 1976). The incorporation of the gypsum into the topsoil by the raking action probably contributed to the dissolution of the salt and resulted in a quicker response to the treatment (Schuman et al. 1994).

Although not all seasons were surveyed, the seedling counts for all three species appear to support the findings of Esler (1993) and Milton (1995) that germination events in the Succulent Karoo are determined by the availability of soil water in the cool season (autumn to spring). Despite adequate rain in autumn 1997 no seedlings of the small-seeded *Ruschia* or *Chaetobromus* were counted in June 1997, 14 months after reseeding in April 1996. This lends support to the results of Esler (1993) and Milton (1995) that persistent seed banks are of minor importance in the reestablishment of perennial plants in the Succulent Karoo. However, there was a relatively good germination event for the larger seeded *Tripteris* in June 1997, indicating some degree of seed bank persistence in this particular species. Of the three reseeded species the best results were obtained for *Tripteris*, with a maximum count of 150 seedlings per 1,000 viable seeds sown. Germination and emergence of *Ruschia* and *Chaetobromus* were generally poor, with maximum counts of 40 and 51 seedlings per 1,000 viable seeds, respectively.

With no established plants competing for resources on these bare areas, the only explanation for the poor emergence in the reseeded-only treatment is the unfavorable soil surface conditions. Only *Tripteris* emerged at all in the reseeded-only treatment, with a maximum count of two seedlings per 1,000 viable seeds. This supports the findings

of a number of workers (Joubert & van Breda 1976; Abusuwar 1995; El-Shorbagy & Suliman 1995) that some form of soil treatment that improves rainfall efficiency generally results in improving the success of reseeding operations. Although gypsum had the greatest impact on water infiltration into these bare areas, the highest average numbers of seedlings for all three species were counted in the gypsum-plus-mulch treatment. Mulching alone or in combination with gypsum significantly increased seedling emergence in all three species. The implication is that water infiltration is not the only problem to be addressed in revegetating denuded areas (Tongway & Ludwig 1996). Sheltered microhabitats (Aguiar et al. 1992; O'Connor 1997), which can provide more than water to the germinating seed and young seedling, have to be created. Organic mulches have been shown to capture sediment, litter, and seeds (Ludwig et al. 1994; Milton 1995), absorb raindrop impact, reduce evaporation, insulate the soil (Abusuwar 1995), and re-create fertile patches (Ludwig & Tongway 1996). The combination of gypsum and mulch in this experiment therefore improved soil moisture conditions and created more favorable microhabitats for germination and establishment.

In a similar vegetation type southeast of the study area, Milton (1994) also found that most seedlings died within a year of emergence, mainly because of lack of follow-up rainfall. At Rietfontein only 5 mm of rain fell between the late winter and early spring period of July and October 1997. Wiegand et al. (1995) suggested that both *Ruschia* and *Tripteris* require more rain during this spring (post-establishment) period for seedling survival. The better survival in the gypsum-only treatment, especially for *Tripteris*, is possibly because these seedlings received more light and were generally more robust than where mulch was applied. The poor recruitment in this experiment begs the question how populations of *Tripteris* and *Ruschia* species are maintained in the matrix vegetation. The answer probably lies in a combination of recruitment site availability (Esler 1993) and rare favorable sequences of rainfall events (Gutterman 1981). Using a simulation model Wiegand et al. (1995) predicted that rainfall would be sufficient for recruitment of *Ruschia* only in 22% of years and for *Tripteris* only in 28% of years over a 93-year simulation period. *Ruschia* and *Tripteris* are both relatively long-lived woody species for which high levels of seedling mortality do not have a major impact on population dynamics (Esler 1993). Other species that showed good emergence and survival in the surrounding degraded rangeland, especially through the very dry winter of 1995 (30–35 mm), were *Aptosimum procumbens* (Lehm.) Steud. (Scrophulariaceae), *Limeum aethiopicum* Burm. (Aizoaceae), *Galenia fruticosa* (L.f.) Sond. (Aizoaceae), and *Galenia sarcophylla* Fenzl (Aizoaceae). These species could be considered for future reseeding experiments in the Succulent Karoo.

The results of this experiment support the findings of a number of workers (Schuman et al. 1994; Milton 1995; Ludwig & Tongway 1996) that by treating the topsoil for improving soil water conditions, the biomass and cover of naturally seeded annuals and perennials will increase. Ephemerals like *Euryops annuus* Compton (Asteraceae) and *Eurystigma clavatum* (L.Bol.) L.Bol. (Mesembryanthemaceae) benefited from the gypsum-improved water infiltration and the seed capture and protection capacity of the mulch. Biennials and short-lived perennials, including *Prenia tetragona* (Thunb.) Gerbaulet, *Delosperma* sp., *Psilocaulon* cf. *dinteri* (Engl.) Schwant., *Drosanthemum eburneum* L.Bol., *Brownanthus ciliatus* (Ait.) Schwant., and *Malephora crassa* (L.Bol.) Jacobsen & Schwant., also established from soil-stored seed banks or from seeds that were washed or blown into the plots. The composition of this pioneer community reflected the composition of the surrounding vegetation and supports Esler (1993), who found that these mat-forming Mesembryanthemaceae of the early successional stages have larger canopy and/or soil seed banks and dormant seeds. The relatively large plant volumes of this naturally seeded community in the gypsum and mulch treatments indicate that seed is not a limiting factor in the revegetation of these bare areas. When favorable microhabitats are created by managing the physical environment (Milton et al. 1994), the natural seed abundance may be sufficient to re-create vegetation patches that will act as sink areas (Ludwig et al. 1994) that further capture and conserve scarce resources (Whisenant & Tongway 1996) and become fertile patches that expand over time. According to Ludwig et al. (1994) it may not be necessary to cover the whole bare area with mulch. Patches of mulch could be deposited while bearing in mind the direction of water flow across the bare area. These mulch patches will act as sink areas for water, sediment, and organic matter, and if 40% of the bare area is covered like this the maximum amount of rainwater will be conserved under conditions of low rainfall (160 mm) (Ludwig et al. 1994).

Without a soil treatment that improves soil water conditions, reseeding bare areas is doomed to failure. Any mechanical soil treatment is costly, and at about R1100 (approximately 2002 US$110) per hectare at an application rate of 5 t/ha, transport costs of 200 km from the fertilizer factory included (G. Uys 2002, Kynoch Fertilizers, personal communication), the gypsum treatment is economically feasible only at a patch scale. Mulching is probably cheaper, especially if locally cut material (e.g., old *Ruschia* shrubs) is used, but will still be a labor-intensive task costed at about R600 (US$60) at an application rate of eight tonnes per hectare, with labor and machinery costs per 2-ton-trailer load estimated at R150 (A. Lund 2002, personal communication). In this regard it would be possible to combine brush-cutting of moribund veld with mulching of bare areas. The ability of the surrounding, mainly nonforage, ephemeral community to expand into the bare areas when environmental conditions are ameliorated has to be exploited. This will avoid the costs of an exogenous seed source, as well as the necessity to protect highly palatable young forage plants from domestic and

wild herbivores. The time it takes for any financial investment to reap benefits is important. It is postulated that the time this revegetation process will take depends first on soil depth and second on the size of the bare area, and therefore distance from a seed source. Some bare areas that are several hectares in size and are in such an eroded state that the bedrock protrudes in places should perhaps be regarded as practically irreversible features.

Conclusions

Mulching of bare areas in the Succulent Karoo enhanced rainfall efficiency and improved germination and emergence of reseeded and spontaneously seeded annuals and perennials. This restoration method has the potential to re-create vegetated areas that will further capture and conserve scarce resources. The gypsum treatment also resulted in improved water infiltration and seedling emergence but might not be a cost-effective option mainly because of transport costs to these remote arid areas. Even with some form of soil treatment, reseeding bare areas in this low rainfall part of the Karoo will remain a risky operation mainly because of the low probability of follow-up rainfall in late winter and spring, which is essential for seedling survival. A worthwhile research avenue would be to evaluate the role of livestock as restoration tools in the treatment of bare areas in the Karoo. There are indications that feeding seed-bearing roughage and herding animals onto these bare areas might be an alternative approach to active restoration.

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