Revegetation of bare patches

H.A. Snyman
University of the Free State

Journal of Arid Environments 55 (2003) 417–432

Journal of Arid Environments

www.elsevier.com/locate/jnlabr/yjare

Revegetation of bare patches in a semi-arid rangeland of South Africa: an evaluation of various techniques

H.A. Snyman*

Department of Animal, Wildlife and Grassland Sciences, University of the Free State, P.O. Box 339, Bloemfontein 9300, South Africa

Received 14 August 2001; received in revised form 2 July 2002; accepted 30 September 2002

Abstract

Semi-arid rangelands, which have retrogressed beyond a certain threshold and could not rest-recover, can only be restored by mechanical inputs helping the re-establishment of vegetation. Therefore, different over-sown species and mechanical restoration methods (hollows-dyker plough, furrows-ripper/sub-soiler and walking-stick planter) were evaluated for the restoration of bare areas on both a sandy and clayish soil type. Changes in species composition and plant density over time (1987/88–1996/97 growing seasons) were determined. The hollows with a rip action in one cultivation operation remained over a longer period and therefore caught more water for better establishment of grass species, compared with making only hollows where it silted up more easily. Establishment was poorest when only the walking-stick planter was used. Although the well establishment of *Eragrostis curvula* over the first 3 years, after 10 years only a few plants survived in both clay and sandy soils. Regardless of cultivation treatment or soil form, *Digitaria eriantha* subsp. *eriantha* survived the best ($p<0.01$) after 10 years and even spread into adjacent areas. *Anthephora pubescens* and *Cenchrus ciliaris* only established successfully in sandy soil. Restoration in semi-arid rangelands is slow and failures are common because of low and unreliable rainfall.

Keywords: Degradation; Hollows; Mechanical implements; Restoration; Rip action; Species composition and density; Walking-stick planter

*Tel.: 27-51-401-2221; fax: +27-51-448-0692.

E-mail address: snymanha@sci.uovs.ac.za (H.A. Snyman).

0140-1963/03/$ - see front matter
doi:10.1016/S0140-1963(02)00286-0

1. Introduction

Rangelands occupy over 70% of the land surface of South Africa (1,219,000 km^2), making them the largest single land use (Snyman, 1999a, pp. 354–379). Sixty-six percent is moderate to seriously degraded (Scheepers and Kellner, 1995). Due to the injudicious use of natural agricultural resources and periodic droughts, the rangelands of South Africa are under enormous pressure (Kellner and Bosch, 1992; O'Connor, 1994). Degraded vegetation (Van der Westhuizen et al., 1999), bush and shrub encroachment (Smit et al., 1999, pp. 246–260; Smit and Rethman, 1999) and erosion (Adler, 1985; Van Oudtshoorn, 1992; Hoffman and Ashwell, 2001) are generally visible symptoms of disturbed rangelands.

In certain rangeland areas of South Africa, natural vegetation degraded to such an extent that the application of management practices or even total withdrawal of grazing, will not have the desired effect on recovery cover and density (Snyman, 1999b; Hoffman and Ashwell, 2001). In these cases, more drastic restoration measures must be applied to help the re-establishment of vegetation, so that the rangeland ecosystem can ensure sustainable animal production once again. These measures should strive towards increasing water infiltration into the soil (Davies et al., 1982; Snyman, 1999c), improving vegetation composition, cover and density (Snyman, 1998; O'Connor et al., 2001), decreasing runoff (Snyman, 1999a, c), creating a better microclimate (Snyman, 2000) and sustainable water balance for the plants (Griffith et al., 1984; Snyman, 1997, 1999c) and eventually control soil erosion (Matthee and Van Schalkwyk, 1984; Hoffman and Ashwell, 2001). Improvement of soil permeability achieved by subsoiling is particularly important in clay soils and can be just as crucial in intensive ranching as it is for arable cropping (Van der Merwe and Kellner, 1999). There is an increasing interest worldwide in the development of farming systems based on sustainable principles (Heitschmidt and Walker, 1996; Snyman, 1998).

Rangeland deterioration is initially very inconspicuous and farmers only realize that the land is deteriorating when drastic changes like bare patches occur (Snyman, 1991; Kellner and Bosch, 1992). There are many approaches to rangeland restoration. The most suitable methods can largely be determined by soil type, climatic conditions, the causes and degree of rangeland deterioration and especially the degree of degradation (Van der Merwe and Kellner, 1999; Tainton et al., 2000, p. 136). Rangeland restoration is mostly an expensive and time-consuming process necessitating thorough pre-planning (Snyman, 1999a). Generally, the farmer or rangeland manager is interested only in methods where the best results can be obtained over a short period, as well as a method that is not very expensive, because rangeland restoration contains an element of risk (Van der Merwe, 1997).

Methods used to shatter the crust on compacted areas in a semi-arid climate can vary from shallow working with a light toothed harrow (Viljoen, 1971), to deep working with a tined implement (Viljoen and Smalberger, 1974), or by making hollows or pits (Snyman, 1999a; Van der Merwe and Kellner, 1999; Tainton et al., 2000). Most of the early rangeland restoration research was either short-term and aimed at specific sites or involved empirical studies applicable to only an immediate problem, such as plant establishment or soil fertility (Snyman, 1999a). It normally did not include long-term basic studies aimed at the processes of plant establishment and community development (Call and Roundy, 1991). Norms for the treatment of bare patches are described mainly for the arid areas of South Africa (Snyman, 1999a). In the United States of America, a great deal of information has been gathered to obtain a norm, especially regarding the depth of cultivation and spacing between furrows made by each implement (Branson et al., 1966; Fisser et al., 1974; Rauzi, 1974, 1975; Griffith et al., 1984). In South Africa, however, there are no accepted guidelines for restoration of degraded patches on large areas in rangelands (Van der Merwe and Kellner, 1999). The purpose of this study was to investigate different over-sown and mechanical restoration methods to restore bare patches for stable vegetation, to again deliver sustainable animal production.

2. Procedure

2.1. Study site

The research was conducted 5 km west of Bloemfontein (29°06′S, 26°57′E, altitude 1350 m) in a semi-arid region of South Africa with an average summer rainfall of 560 mm (of which 55% falls during the period January–April). In January, the average maximum daily temperature ranges from 30°C to 33°C. In July it is approximately 17°C. Extremes of 41°C in January and 28°C in July have been recorded. On average, frost occurs on 119 days each year (Schulze, 1979).

Two different soil forms were investigated, namely a Bloemdal (Roodeplaat family—3200) and Valsrivier (Goedemoed family—1120) (Soil Classification Working Group, 1991) with a 4% slope. The Bloemdal form with three distinct horizons (A: 0–200 mm, B1: 200–600 mm and B2: 600–800 mm) contained 10.6%; 19.0% and 38.8% clay, respectively, and the respective bulk densities were 1484, 1563 and 1758 kg m^{-3}. The three distinct horizons (A: 0–200 mm, B1: 200–400 and B2: 400–900 mm) of the Valsrivier form contained 22%, 38% and 36% clay, respectively, and the respective bulk densities were 1651, 1688 and 1788 kg m^{-3}. The most important soil forms of rangeland in the central grassland area of South Africa are Bloemdal and Valsrivier.

On every soil form, a bare patch of about 60 m × 60 m with very sparse vegetation cover was studied over a period of 10 years (1987/88–1996/97 growing seasons). The reasons for the patches being bare were mainly overgrazing and trampling near water points. These degraded rangelands were therefore due to high concentrations of animals over a long period of time. Only single tufts of *Aristida congesta* subsp. *congesta* and *Lycium tenui* (Snyman, 1999c) plants occurred in soil with visible serious surface erosion (Snyman, 2000). In an undisturbed state, this rangeland type is described as typical dry sandy Highveld Grassland (Bredenkamp and Van Rooyen, 1996, p. 41). The experimental study plots were not further grazed over the 10-year period.

2.2. Methods

The mechanical implement used was a combination of a ripper (sub-soiler) and altered hollow maker or dyker plough as described by De Jager (1982), Van der Merwe (1997) and Van der Merwe and Kellner (1999). This specially designed implement is one of a few available where a rip action and the making of hollows or pits can occur in a single action. The ripper part consisted of a one-tine ripper, which can loosen up to a depth of 400 mm. The hollows or pits consisted of elongated hollows (1 m $\times$ 30 mm) that are 200 mm deep and repeated every meter.

A walking-stick planter was used. The planter comprised of a hollow pipe that also has a specially designed pointed structure at one end that releases a small quantity of seed (prefer coated seeds) whenever the point makes contact with the soil. Used properly, it deposits the seed at a predetermined depth in the soil and can be effective in reseeding bare patches in the veld (Snyman, 1999a; Tainton et al., 2000). The seed in this study was placed within the hollows (10 mm deep) with a minimum of soil disturbance and 200 mm apart.

The three mechanical restoration methods applied consisted therefore of (1) a ripper action plus hollows in a single operation, (2) the making of hollows without ripping and (3) the use of the walking-stick planter without cultivation. These cultivated treatments were conducted randomly in blocks of 16.5 m $\times$ 16.5 m, with three replications. The cultivation rows within each mechanical treatment were spaced 1.5 m apart.

The species used in over-sowing trials consisted of *Anthephora pubescens* (no. 2701), *Cenchrus ciliaris* (Molopo), *Chloris gayana*, *Cynodon dactylon* (Tifton 44), *Digitaria eriantha* subsp. eriantha (Irene), *Eragrostis curvula* (Ermelo), *E. tef* (Old Brown), *Medicago sativa* (Granada) and *Panicum maximum* (Green Panic) established at an average of 2 kg ha^{-1} in the cultivation strips or rows with a control where no over-sowing took place.

Every cultivated row or strip (16.5 m long) was established separately with a specific species, while the different species were established randomly within every cultivation treatment with three replications (Fig. 1). The experimental design for each soil form was a 3 $\times$ 10 (cultivation and planted species) factorial experiment (Winer, 1974), with three replications for cultivation and three for sown species. Analysis of variance was conducted where all interactions for the variables were included. Density of all species (over-sown and pastures with vegetation and native pastures) were also analysed separately for the different cultivations after 10 years. The Number Cruncher Statistical System (2000) software package were used in most analyses.

Just after cultivation (making hollows and ripping) on 6 October 1987, the seed was over-sown by hand against the sides of the hollows to prevent waterlogging. At the same time, the walking-stick planter planted the seed. No fertilizer was applied. During the month previous to planting 158 mm rain occurred and therefore the seed was established in moist soil.

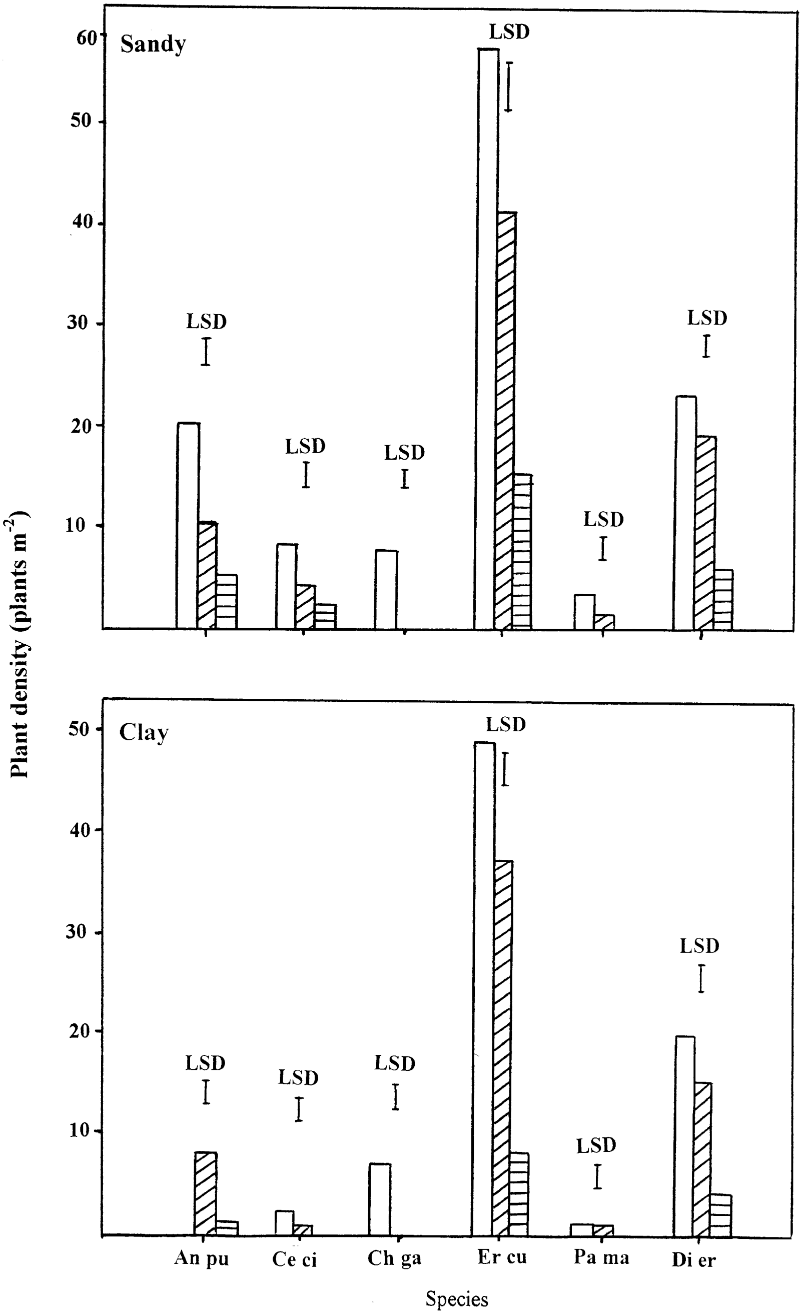

Fig. 1. Density (plants m^{-2}) of different over-sown species, 3 years after cultivation, on a sandy and clay soil. Species: *An pu* = *Anthephora pubescens*; *Ce ci* = *Cenchrus ciliaris*; *Ch ga* = *Chloris gayana*; *Er cu* = *Eragrostis curvula*; *Pa ma* = *Panicum maximum*; *Di er* = *Digitaria eriantha* subsp. *eriantha*. Cultivation treatments: □ = Hollows + rip; ▨ = Hollows and ⊟ = Walking-stick planter. Least significance (LSD) is calculated at the 1% level.

2.3. Data collection

A survey was done according to the wheel point method (Tidmarsh and Havenga, 1955) during which the nearest plant was noted to obtain the frequency (%) of the plants within each cultivation treatment. For each cultivation treatment, 300 points were taken (100 per replication) (Hardy and Walker, 1991). The surveys were conducted at the end of the growing seasons (April–June).

The quadrate method ($0.5\,m \times 0.5\,m$) was used to determine the density of each plant species in a treatment, as well as the density of the total vegetation community. The quadrates were placed along lines where the soil had been cultivated by a certain mechanical treatment (Van der Merwe and Kellner, 1999). There were 180 quadrates for each cultivated treatment (60 per replication and 6 quadrates were placed in each cultivated row). The success of the over-sown species as well as the increase of the species growing naturally, were monitored during the first, second, third and tenth year after establishment as described above. The germination and establishment for the over-sown pastures were determined by counting all seedlings per species every second month over the first two seasons within the quadrats as described above. At the end of the third and tenth season the same was done to determine plant survival.

3. Results

3.1. Rainfall

The cultivation growing season (1987/88) was accompanied by above average rainfall, causing generally good plant establishment. This season received 80% more rainfall than the long-term average for the study area. During February and March 1988, 476 and 137 mm rainfall occurred respectively, while the long-term average for these two months was only 83 and 84 mm, respectively. The following two seasons' rainfall was close to the long-term average with a good seasonal distribution. On average over 10 years (1987/88–1996/97 growing seasons), 623 mm rainfall occurred per annum versus the long-term average of 560 mm per annum for the study area. Four growing seasons did receive below average rainfall, with those of the 1992/93 and 1994/95 growing seasons particularly low, at 26% and 27% less than the long-term average, respectively.

3.2. Plant density and frequency

3.2.1. First two seasons

The survival of over-sown species after a few years determines the success of veld restoration and therefore the cultivation of the first two seasons will be discussed in less detail.

E. curvula, E. tef and *M. sativa* germinated the best at initial establishment, where 68, 72 and 86 plants m^{-2}, respectively, occurred on average after 3 months on sandy and clay soils where both hollows and ripping took place. Where only hollows were made, the germination was on average 25% poorer for the above three species. Regardless of the significantly high rainfall that occurred during February 1988 and March 1988, most of the species that germinated in the hollows survived. During March 1988, sites where waterlogging and poor germination occurred were re-established. Just after showers, it was noticeable that hollows that were combined with ripping were almost never filled with water that quickly filtrated into the soil. In the cultivation treatment where only hollows were made, the hollows were constantly filled with water after a rain shower and remained so for fairly long periods of time.

At the end of the first season, a good stand of *A. pubescens* (40 plants m^{-2}), *C. gayana* (45 plants m^{-2}), *C. ciliaris* (25 plants m^{-2}) and *D. eriantha* subsp. *eriantha* (45 plants m^{-2}) also occurred on sandy cultivated soils, apart from the three species mentioned above. Where only hollows were made, the germination was poorer for all species than when both hollows and a ripper action were used. *A. pubescens* and *C. ciliaris* established poorly in clay soil than in sandy soil, while *D. eriantha*, *C. gayana* and *E. curvula* showed no preference for clay content. *P. maximum* and *C. dactylon* established very poorly in both soil forms and different cultivations. From the walking-stick planter seeding technique, the establishment or survival of all species was very poor in all treatments after the first year.

During the second season, *M. sativa* drastically started to decrease and after 2 years no plants occurred in any treatment after initially being one of the best stands. *E. tef* did not germinate again during the second season, but served as a good foster crop for soil preparation for follow-up species.

3.2.2. Third season

Plant density was significantly ($p < 0.01$) influenced by cultivation for most species and for both soil forms (Fig. 1). The beneficial influence of a ripper action together with the making of hollows appeared after 3 years to be best for a successful establishment of plant species. A significant interaction ($p < 0.01$) was obtained on the sandy soil between plant densities of all species with the cultivation treatments, which was not ($p > 0.05$) the case for the clay soil.

Plants wilted sooner and even died where only hollows were made. Fig. 1 again shows that the establishment of *C. gayana, D. eriantha* subsp. *eriantha* and *E. curvula* was not influenced much by clay content of the soil. The species that survived best after 3 years in sandy soils were *A. pubescens*, *E. curvula* and *D. eriantha. A. pubescens* and *C. ciliaris* grew very poorly in clay soils, while *P. maximum* and *C. gayana* generally did not survive successfully ($p > 0.05$) regardless of the clay content of the soil. *M. sativa, C. dactylon* and *E. tef* totally disappeared after three years in all treatments.

No established tufts of *C. gayana* survived after 3 years where only hollows had been made. This species therefore preferred a well-prepared seedbed for successful establishment. Survival after 3 years was very poor for all species where they were planted by the walking-stick, except for *E. curvula, A. pubescens* and *D. eriantha* that survived relatively well ($p < 0.01$) after 3 years on sandy soils.

In the control cultivation treatments, where no plants were established, only *A. congesta* subsp. *congesta* and *C. virgata* occurred after 3 years. A higher density of these pioneer grasses in the cultivated areas could also have a negative effect, as these grasses may be in competition with more climax grasses, which is detrimental to the establishment of climax grasses. On sites where plants were introduced by the walking-stick, *E. lehmanniana* (16 plants m^{-2}), *D. argyrograpta* (12 plants m^{-2}) and *Brachiaria eruciformis* (10 plants m^{-2}) started to dominate after 3 years while vegetation density was still very low. The average densities on these sites were only 15 plants m^{-2}.

3.2.3. After 10 years

The hollow plus ripping treatment for both the sandy and clay soil forms had a significantly ($p<0.01$) higher total plant density than the other two treatments (Fig. 2). A significant interaction ($p<0.01$) was obtained for both soil forms between plant density and cultivation. The lowest ($p<0.01$) total plant density occurred where no cultivation was applied (walking-stick) on both clay and sandy soils. In all the cultivation treatments, clay soil had a lower (14% on average) plant density than the sandy soil (Fig. 2). The plant density on sandy soil increased more effectively where soil was cultivated (hollows plus rip) (Fig. 2).

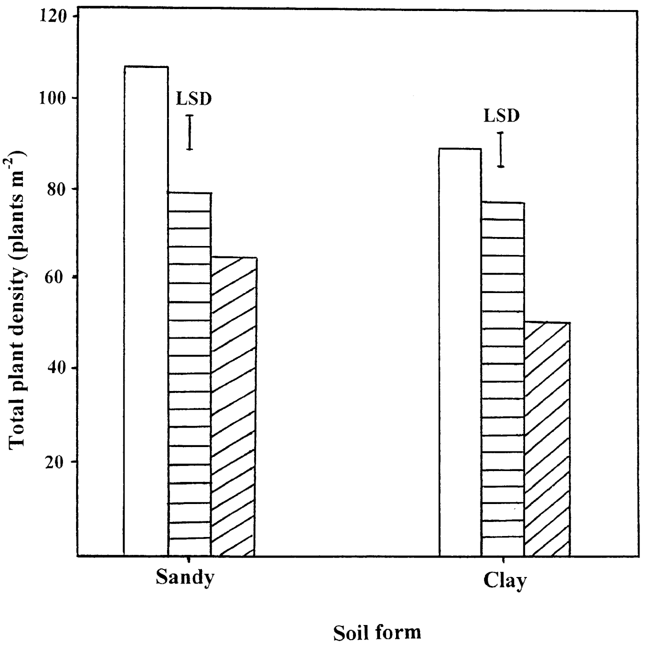

Fig. 2. Total plant density (plants m^{-2}) for the different cultivations 10 years after cultivation, on a sandy and clay soil form. Cultivation treatments: □ = Hollows + rip; ▤ Hollows and ▨ = Walking-stick planter. Least significance (LSD) is calculated at the 1% level.

After 10 years, *A. congesta* subsp. *congesta* contributed most to the total plant density for all the cultivation treatments and soil forms. This poorly perennial species formed very small tufts (average of 5 mm diameter) and its average contribution was 37% of total plant density in all treatments.

In Table 1, the frequency of the different species in each cultivation treatment is presented separately for the clay and sandy soils. Table 1 indicates that the over-sown grass species survived on both soil forms better and increased where cultivation was practiced. The over-sown species established better on sandy soils, regardless the cultivation, than on clay soils. *D. eriantha* subsp. *eriantha* formed an average of 27%

Table 1
Species frequency (%) 10 years after cultivation on a sandy and clay soil for each cultivated treatment

Species	Soil form					
	Sandy			Clay		
	Hollows + rip	Hollows	Walking-stick	Hollows + rip	Hollows	Walking-stick
Anthephora pubescens	12.62[a]	4.17[b]	0.31[c]	2.18[a]	1.24[a]	0.21[a]
Cenchrus ciliaris	0.36[a]	0.20[b]	0.11[c]			
Digitaria eriantha subsp. eriantha	28.04[a]	18.30[b]	11.21[c]	26.14[a]	6.92[b]	0.62[c]
Eragrostis curvula	0.08[a]	0.13[a]	0.07[a]	0.08[a]	0.06[a]	0.01[b]
Panicum maximum	0.08[a]	0.09[a]	0.07[a]	0.08[a]	0.05[a]	0.01[b]
Total planted species	41.18	22.89	11.77	28.48	10.27	0.85
Climax						
Cymbopogon plurinodis	0.20[a]	3.15[a]	2.16[a]	1.00[a]	2.14[a]	3.12[a]
Digitaria eriantha	0.91[a]	6.14[b]	0.90[a]	1.11[a]	3.16[a]	0.12[b]
Panicum stapfianum	4.15[a]	2.22[a]	1.42[a]	5.83[a]	3.40[a]	1.29[b]
Sporobolis fimbriatus	6.15[a]	3.42[b]	1.72[c]	4.14[a]	1.15[b]	1.99[b]
Themeda triandra	12.50[a]	14.03[a]	24.43[b]	6.69[a]	25.16[b]	33.82[c]
Total climax	24.91	28.96	30.63	18.77	35.01	40.34
Subclimax						
Digitaria argyrograpta	2.44[a]	2.11[a]	8.16[b]	3.11[a]	8.42[b]	8.84[b]
Eragrostis lehmanniana	12.13[a]	19.12[b]	18.99[b]	15.98[a]	15.99[a]	18.29[a]
Eragrostis obtusa	1.00[a]	1.22[a]	2.11[a]	3.14[a]	3.29[a]	2.01[a]
Total subclimax	15.57	22.45	29.26	23.23	27.70	29.14
Pioneer						
Aristida congesta subsp. *Congesta*	10.14[a]	12.96[a]	12.00[a]	16.96[a]	12.91[a]	11.99[a]
Brachiaria eruciformis	6.14[a]	5.18[a]	9.15[b]	6.18[a]	7.23[a]	6.15[a]
Chloris virgata	0.80[a]	6.14[b]	2.14[c]	2.00[a]	4.17[a]	2.11[a]
Lycium tenue	0.13[a]	0.14[a]	0.78[b]	0.14[a]	0.21[a]	3.16[b]
Tragus koelerioidess	1.11[a]	1.16[a]	4.14[b]	4.12[a]	2.14[a]	4.15[a]
Walafrida saxatilis	0.02[a]	0.12[b]	0.13[b]	0.12[a]	0.36[b]	2.11[c]
Total pioneer	18.34	25.70	28.34	29.52	27.02	29.67
Total: all species	100	100	100	100	100	100

Percentages within a row for each soil form, with different superscripts differ significantly ($p \leqslant 0.01$).

of the total plant composition for sandy and clay soils where both hollows and ripping took place. This species had almost the same species frequency on both sandy and clay soils where hollows plus rip action were performed. Where hollows only were made, *D. eriantha's* contribution towards the total species composition was significantly ($p<0.01$) lower than when both hollows were made and ripped (Table 1).

C. ciliaris and *A. pubescens* established very poorly on clay soils, regardless of the cultivation treatment (Table 1), with no survived plants of *C. ciliaris* after 10 years. After 10 years, only a few plants of *E. curvula* and *P. maximum* occurred in both clay and sandy soils.

In uncultivated treatments, *Themeda triandra* (a sominant climax species) established considerably better ($p<0.01$) on both soil forms than where hollows were made together with a ripper action. The species composition was dominated by subclimax and pioneer species in the uncultivated treatments. *A. congesta* and *E. lehmanniana* increased relatively rapidly, regardless of the cultivation treatment or soil form. The only shrubs namely *Lycium tenui* and *Walafrida saxatilis* increased significantly ($p<0.01$) in the clay soil without cultivation (Table 1).

The density of the three over-sown grass species (*A. pubescens, C. ciliaris* and *D. eriantha* subsp. *eriantha*) that survived and increased best is schematically presented in Fig. 3 together with those of the rest of the species. *D. eriantha* formed very large tufts (average of 120 mm diameter) in all cultivation treatments over the experimental period, which was to its detriment in the total density statement. *A. congesta* only formed very small tufts (average of 5 mm diameter), which is to this species' advantage if density per area is compared to that of other species. Fig. 3 again shows that this species establishes equally well on sandy and clay soils in all cultivation treatments. *D. eriantha* noticeably started to spread from the cultivation strips to the adjacent area.

After 10 years, it was interesting to note that *D. eriantha* established equally well both where hollows were made together with a ripper action or where only hollows were made regardless of soil form. Where no cultivation took place, the survival of this species was reasonable (6 plant m^{-2}), but still the best ($p<0.01$) on the sandy soil of all the over-sown species.

A. pubescens and *C. ciliaris* only survived ($p>0.01$) on sandy soils and where hollows were made together with a rip action ($p<0.01$) (Fig. 3). Under no cultivation, these two species survived poorly and no *C. ciliaris* plants occurred on clay soils. Of these three species, *C. ciliaris* was the least ($p<0.01$) established after 10 years, regardless of cultivation or soil form. No *C. ciliaris* plants survived in any cultivation treatment in the clay soil.

Generally, more plants per area occurred where no over-sowing took place ($p<0.01$), but their tufts were smaller than those of the over-sown species (Fig. 3). For example, *A. congesta*, which dominated after 10 years, formed an average of 51% of the species composition and 38% of the total composition of all species where hollows were made together with a ripper action. When no cultivation (walking-stick) was applied, *A. congesta* formed 41% of the rest of the species and 38% of the total species density.

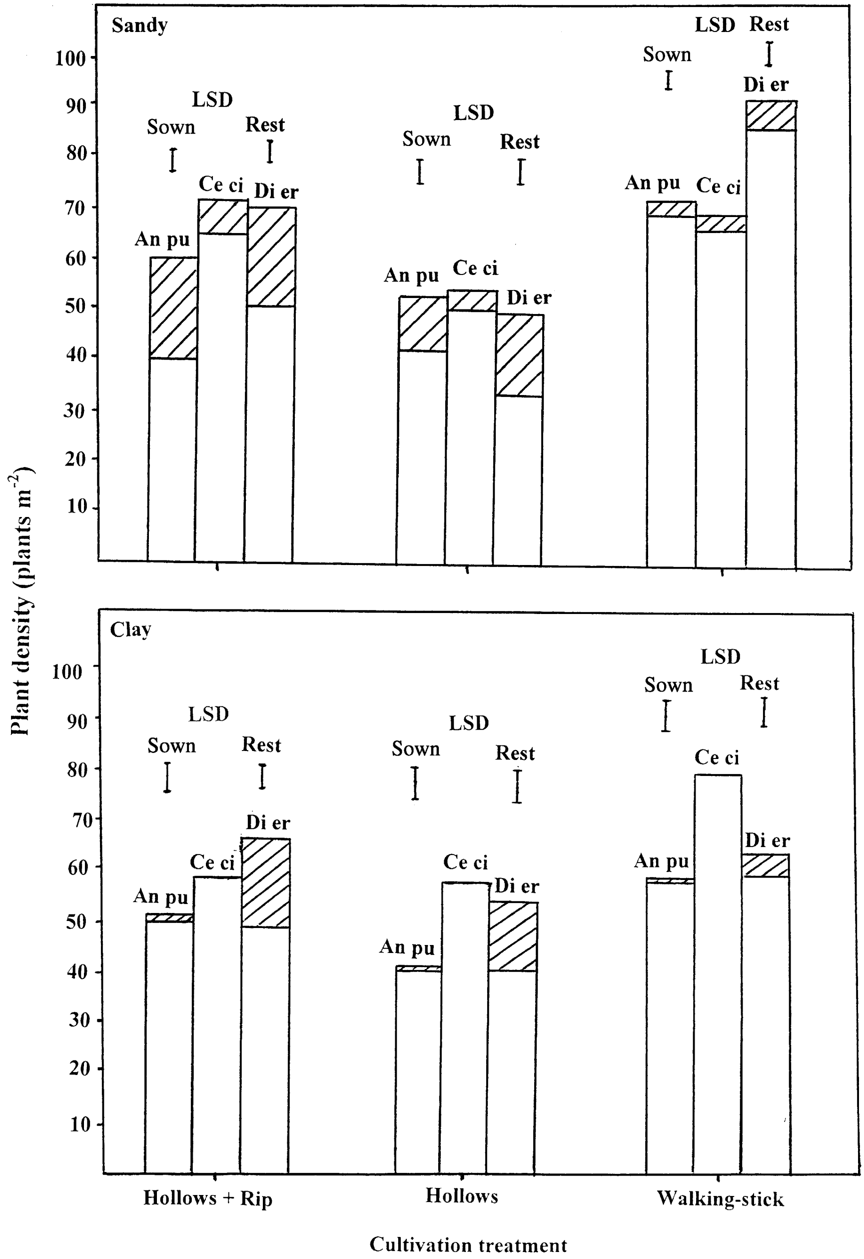

Fig. 3. Density (plants m^{-2}) of the three best established over-sown species, as well as the total density of the rest of the species, on a sandy and clay soil, for the different cultivations after 10 years. Species: *An pu* = *Anthephora pubescens*; *Ce ci* = *Cenchrus ciliaris* and *Di er* = *Digitaria eriantha* subsp. *eriantha*. ▨ = Over-sown; □ = Rest of species. Least significance (LSD) is calculated at the 1% level.

For the treatment where hollows plus a rip action was performed on sandy soil, it was interesting that in 56%, 5% and 88% of the hollows, plants of, respectively, *A. pubescens, C. ciliaris* and *D. eriantha* survived (if only one plant occurred of a species in a hollow, it was noted as being present). Where only hollows were made, *A. pubescens, C. ciliaris* and *D. eriantha*, respectively, occurred in 26%, 3% and 19% of the hollows on sandy soils. On clay soils, occurrences of these species were much lower as already discussed.

4. Discussion and conclusions

According to the results of this study, plant establishment and survival was overall better when a hollow cultivation technique with a ripper action (400 mm depth) were applied in one operation. The total plant density of 88 plants m^{-2} obtained after 10 years on clay soils where hollows plus ripper action were performed coincided with the results (80 plants m^{-2}) obtained by Van der Merwe and Kellner (1999). Their study also was performed on clay soil (semi-arid climate) with hollows after 3–10 years. There are still many views on depth and distance between cultivations (hollows and furrows) (Snyman, 1999a; Tainton et al., 2000), which are also very important because these factors influence the results of restoration to a considerable extent (Van der Merwe and Kellner, 1999). Van der Merwe and Kellner (1999) recommended that the depth of cultivation should be 200 mm or more and the cultivation width not less than 2 m, which is the same as that applied for semi-arid areas by Snyman (1999a). In South Africa, great success was achieved by using different types of dyker plough in arid regions, in making small shallow pits scattered across the soil surface (De Jager, 1982; Snyman, 1991). This is supported by a survey of restoration methods attempted by rangeland managers in southern Africa and carried out by Van der Merwe (1997) and Van der Merwe and Kellner (1999). The implement types they evaluated included chisel ploughs, mounted tandem disc harrows, grooved disc harrows, dyker ploughs, rippers, planters, mouldboard ploughs, cultivators and disc ploughs. The results showed that cultivation with the dyker plough was the most effective in clayish soils and that the ripper cultivation techniques were the most suitable on sandy soils, provided the appropriate settings were used on the instruments.

It seems that the hollows made in this study catch more water and prevent the water from running down, increasing the soil-water content and facilitating plant establishment. As much as 30–50% of the rain falling on bare areas without cultivation may be lost as runoff (Snyman, 1999a). Regenerative measures should, therefore, normally aim to increase water infiltration into the soil by some form of cultivation. The hollows with a rip action in one operation remain over a longer period and therefore catch more water, compared with making only hollows where deposited soil silts up more easily.

Rangeland restoration is a long-term process in the semi-arid areas and will not again deliver sustainable animal production after only a short period. Failures are common in arid and semi-arid areas because of low and unreliable rainfall (Snyman, 1999a). After a 10-year period, vegetation was still unstable and still dominated by many pioneer species. The solution is to rather continually encourage water infiltration by applying progressive cultivation methods. The advantages of spreading a progressive method over a number of years are to continually encourage water infiltration to spread cultivation costs and to continually improve the seedbed (Snyman, 1999a). Because the grazing capacity of these rangeland types is relatively low, only inexpensive conservation measures are justified.

Most research shows that it is essential to introduce seed together with mechanical cultivation for the rapid restoration of bare patches (Matthee and Van Schalkwyk, 1984; Van Coller and Aspinall, 1990; Snyman, 1999a) as this study also indicates. The poor plant establishment obtained without applying soil cultivation again emphasizes the importance of creating a favourable micro-climate as soon as possible on degraded rangeland. Soil temperatures as high as 52°C at a depth of 50 mm have, for example, been measured on soils of rangeland in poor condition in semi-arid areas, compared to temperatures of only 44°C where the rangeland is in good condition (Snyman, 1999a). Temperatures of 65°C have been measured in the topsoil on bare areas (Snyman, 2000). Such high soil temperatures can severely restrict the recovery of bare areas or of areas with a poor plant cover.

Most of the research results support the findings obtained in this study, namely that there is no "wonder" crop for all veld restoration circumstances. There are a number of species that can be successfully over-sown on a wide range of soil and climatic conditions. The success of a restoration operation, and more specifically the survival of over-sown species, must be evaluated over a long period. Though *E. curvula* had the best establishment over the first 3 years, it disappeared in some treatment areas after 10 years. This species never formed large tufts over the study area, but remained as a lot of small tufts. This is in contrast with many other researchers, who found this species to be successful for various veld restoration programmes (Viljoen, 1971; Viljoen and Smalberger, 1974; Grunow et al., 1983; Dickinson et al., 1990; Van Coller and Aspinall, 1990). *D. eriantha* subsp. *eriantha* showed continuous high survival over the study period, regardless of the clay content of the soil or cultivation treatment. Van Coller and Aspinall (1990) in the Eastern Cape determined the same tendency. According to Snyman (1994), *D. eriantha* subsp. *eriantha* was the most productive and actively growing over-sown species without any fertilization. It used water very efficiently on the same soil form as in this study. A similar trend was found by Dannhauser (1991a) on marginal soils in a semi-arid climate. This species rapidly formed very large tufts during the study and produced much seed annually. After 10 years, this species also spread from the established rows into adjacent areas, regardless of difficult establishment mentioned by various researchers (Dannhauser, 1981, 1982; Dickinson et al., 1990).

A. pubescens and *C. ciliaris* showed that they could only be successfully over-sown on sandy soils. Various other researchers shared this finding (Dickinson et al., 1990; Snyman, 1994). Snyman (1994) found that *A. pubescens* maintained a reasonably consistent production and water-use efficiency throughout seasons, regardless of soil water conditions. This suggests its use as an excellent potential restoration species in areas of lower rainfall. The relatively low yield and water-use efficiency in terms of phytomass production (Snyman, 1994) is counterbalanced by its drought tolerance (Dannhauser et al., 1987) and its high crude protein content (Snyman, 1994), which may explain the high palatability status of this species (Dannhauser, 1991b).

A species like *E. tef* can be considered as a foster crop serving as a basis for successive species, while this study showed that *P. maximum* and *C. dactylon* can be risky for successful cultivation. Though *C. gayana* is often used in the stabilizing of waterways, it was very sensitive to poorer soil cultivation, which may be ascribed to its stringy appearance and poor perenniality and may require more water. The cold sensitivity of *P. maximum* (Dickinson et al., 1990; Dannhauser, 1991b) and its delayed bud break (Snyman, 1994) may contribute to the poor establishment of this species. These disadvantages may limit its establishment in colder areas.

Though the over-sown species performed and survived the best with soil cultivation, they were also accompanied by many pioneer species. Where no cultivation took place, *T. triandra* and other climax grasses started stabilizing the bare soil after 10 years. This is supported by the results of Van der Merwe (1997) that states that climax grasses do not establish rapidly on bare patches where crust formation has already occurred.

According to Griffith et al. (1984), stocking influences the extent to which the cultivation procedures used will assist in trapping seed and will establish new seedlings and thereby, the density and diversity of the cover. The type of management applied to restored rangeland will determine the success of the reinforcement exercise. Management should be directed at the needs of the newly introduced species rather than at the species of the existing vegetation and more importantly, should be directed at providing the newly seeded species with an opportunity to produce a seed crop (Snyman, 1999a). Some researchers recommend that the treated areas be withdrawn for at least 1 year following good rainfall, while in the second and third year, the areas should only be grazed lightly (Van der Merwe, 1997; Van der Merwe and Kellner, 1999).

References

Adler, E.D., 1985. Soil conservation in South Africa. Department of Agriculture and Water Supply, Bulletin 406. Government Printers, Pretoria, South Africa, 44pp.

Branson, F.A., Miller, R.T., McQueen, I.S., 1966. Contour furrowing, pitting and ripping on rangelands of the Western United States. Journal of Range Management 19, 182–190.

Bredenkamp, G., Van Rooyen, N., 1996. Dry sandy Highveld Grassland. In: Low, A.B., Rebelo, A.G. (Eds.), Vegetation of South Africa, Lesotho and Swaziland. Department of Environmental Affairs and Tourism, Pretoria, South Africa, 85pp.

Call, C.A., Roundy, B.A., 1991. Perspectives and processes in revegetation of arid and semi-arid rangelands. Journal of Range Management 44, 543–549.

Dannhauser, C.S., 1981. Invloed van saaidiepte en grondtoestand op die ontkieming van *Digitaria eriantha* subsp. *eriantha*. Proceedings of the Grassland Society of South Africa 16, 75–78.

Dannhauser, C.S., 1982. Die geskiedenis van Smutsvingergras met spesiale verewysing na die Hoëveldstreek. Proceedings of the Grassland Society of South Africa 17, 17–20.

Dannhauser, C.S., 1991a. The herbage yield and quality of three grass species on two marginal maize soils at Potchefstroom. Journal of the Grassland Society of Southern Africa 8, 120–121.

Dannhauser, C.S., 1991b. Die bestuur van aangeplante weidings in die somerreënvaldele. Pietersburg, Review Printers, South Africa, 175pp.

Dannhauser, C.S., Van Rensburg, W.L.J., Opperman, D.P.J., Van Rooyen, P.J., 1987. Die produksie van Smutsvingergras in die Wes-Transvaal. Journal of the Grassland Society of Southern Africa 4, 148–150.

Davies, B., Eagle, D., Finney, B., 1982. Soil Management, 4th Edition. Farming Press Limited, Ipswish, Suffolk, 287pp.

De Jager, D.G., 1982. Herwinning van ontblote veld met die Grootfontein happloeg. Karoo Agriculture 2 (3), 23–25.

Dickinson, E.B., Hyam, G.F.S., Breytenbach, W.A.S., 1990. Die Kynoch weidingshandleiding. CTP Press, Cape Town, South Africa. 423pp.

Fisser, H.G., Mackey, M.H., Nichols, J.T., 1974. Contour furrowing and seeding on nuttall saltbush rangeland of Wyoming. Journal of Range Management 27 (6), 459–462.

Griffith, L.W., Schuman, G.E., Rauzi, F., Baumgarther, R.E., 1984. Mechanical renovation of shortgrass prairies for increased herbage production. Journal of Range Management 38 (1), 7–10.

Grunow, J.O., Pieterse, P.A., De Witt, C.C., 1983. Preference rating and other characteristics of a few promising *Eragrostis curvula* ecotypes as determined by grazing sheep. Proceedings of the Grassland Society of Southern Africa 18, 61–63.

Hardy, M.B., Walker, R.S., 1991. Determining sample size for assessing species composition in grassland. Journal of the Grassland Society of Southern Africa 8, 70–73.

Heitschmidt, R.K., Walker, J.W., 1996. Grazing management: technology for sustaining rangeland ecosystems. Rangeland Journal 2, 194–215.

Hoffman, M.T., Ashwell, A., 2001. Nature Divided Land Degradation in South Africa. University of Cape Town Press, Cape Town, South Africa, 168 pp.

Kellner, K., Bosch, O.J.H., 1992. Influence of patch formation in determining the stocking rate for southern Africa grasslands. Journal of Arid Environments 22, 99–105.

Matthee, J.F.la G., Van Schalkwyk, C.J., 1984. Introduction to Soil Conservation. Department of Agriculture, Bulletin 339. Government Printers, Pretoria, South Africa, 126pp.

O'Connor, T.G., 1994. Composition and population responses of a African savanna grassland to rainfall and grazing. Journal of Applied Ecology 31, 155–191.

O'Connor, T.G., Haines, L.M., Snyman, H.A., 2001. Influence of precipitation and species composition on phytomass of a semi-arid African grassland. Journal of Ecology 89, 850–860.

Rauzi, F., 1974. Mechanical and chemical range renovation in south-eastern Wyoming. Journal of Range Management 27 (1), 48–52.

Rauzi, F., 1975. Severe mechanical and chemical range renovation in north-eastern Wyoming. Journal of Range Management 28 (4), 319–326.

Scheepers, J.C., Kellner, K., 1995. Biological issues. In: Arluthmot, F.D. (Ed.), Report of the ESA Working Group on Land Degradation. Department of Agriculture, Pretoria, South Africa: Directorate of Resource Conservation, 74pp.

Schulze, E.R., 1979. Climate of South Africa. Park 8. General Survey. Weather Bureau, South Africa.

Smit, G.N., Rethman, N.F.G., 1999. The influence of tree thinning on the establishment of herbaceous plants in a semi-arid savanna of southern Africa. African Journal of Range and Forage Science 16 (1&2), 22–31.

Smit, G.N., Richter, C.G.F., Aucamp, A.J., 1999. Bush encroachment: an approach to understand and managing the problem. In: Tainton, N.M. (Ed.), Veld Management in Southern Africa. Scottsville, University of Natal Press, South Africa, 472pp.

Snyman, H.A., 1991. Evaluering van grasspesies vir die herwinning van kaal kolle in die semi-ariede grasveldgebiede. Glen Agric 10 (1), 1–5.

Snyman, H.A., 1994. Evapotranspiration, water-use efficiency and quality of six dryland planted pasture species and natural vegetation in a semi-arid rangeland. African Journal of Range and Forage Science 11 (3), 82–88.

Snyman, H.A., 1997. The influence of range condition on the hydrological characteristics in a semi-arid rangeland. Proceedings of the XVIII International Grassland Congress, Canada 2 (23), 1–2.

Snyman, H.A., 1998. Dynamics and sustainable utilization of the rangeland ecosystem in arid and semi-arid climates of southern Africa. Journal of Arid Environments 9, 645–666.

Snyman, H.A., 1999a. Soil erosion and conservation. In: Tainton, N.M. (Ed.), Veld Management in Southern Africa. University of Natal Press, Scottsville, South Africa, 472pp.

Snyman, H.A., 1999b. Short-term effects of soil water, defoliation and rangeland condition on productivity of a semi-arid rangeland in South Africa. Journal of Arid Environments 43, 47–62.

Snyman, H.A., 1999c. Quantification of the soil-water balance under different veld condition classes in a semi-arid climate. African Journal of Range and Forage Science 16 (2&3), 108–117.

Snyman, H.A., 2000. Soil-water utilisation and sustainability in a semi-arid grassland. Water South Africa 76 (3), 333–341.

Soil Classification Working Group, 1991. Soil classification: a taxonomic System for South Africa. Department of Agriculture Development, Pretoria, South Africa, 262pp.

Tainton, N.M., Drewes, R.H., Rethman, N.F.G., Rethman, N.F.G.,Donaldson, C.H., 2000. Radical veld improvement. In: Tainton, N.M. (Ed.), Pasture Management in South Africa. University of Natal Press, Scottsville, South Africa, 355pp.

Tidmarsh, C.E.M., Havenga, C.M., 1955. The wheel-point method of survey and measurement of semi-open grasslands in Karoo vegetation in South Africa. Botanical Survey of South Africa, Memoire 29. Government Printers, Pretoria, South Africa, 49pp.

Van Coller, A.T., Aspinall, J.E., 1990. Die herwinning van harde kolle in die Oos-Kaap. Döhne Agric 12 (1), 1–3.

Van der Merwe, J.P.A., 1997. The development of a data base and expert system for rangeland reinforcement practices in southern Africa. M.Sc. Thesis, Plant and Soil Sciences, Potchefstroom University for Christian Higher Education, Potchefstroom, South Africa, 169pp.

Van der Merwe, J.P.A., Kellner, K., 1999. Soil disturbance and increase in species diversity during rehabilitation of degraded arid rangelands. Journal of Arid Environments 41, 323–333.

Van der Westhuizen, H.C., Van Rensburg, W.L.J., Snyman, H.A., 1999. The quantification of rangeland condition in a semi-arid grassland of southern Africa. African Journal of Range and Forage Science 16 (2&3), 49–61.

Van Oudtshoorn, F., 1992. Guide to Grasses in South Africa. Briza Publishers, Cape Town, South Africa, 301pp.

Viljoen, L., 1971. Meganiese bewerking van kaal kolle om biologiese herstelling te bewerkstellig, Bulletin 66, Department Agriculture. Government Printers, South Africa, 12pp.

Viljoen, L., Smalberger, L.J.B., 1974. Herwinning van kaal kolle en yl bedekte veld deur progressiewe bewerkingsmetodes, Bulletin 108, Department Agriculture. Government Printers, South Africa, 13pp.

Winer, B.J., 1974. Statistical Principles in Experimental Design. McGraw-Hill, London. 216–218pp.