

**THE DYNAMICS OF CERTAIN GRASS SPECIES USED
DURING THE RESTORATION OF DEGRADED SEMI-
ARID RANGELANDS**

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Opsomming

Die dinamika van sekere grasse wat gebruik word gedurende die restourasie van gedegradeerde semi-ariëde weivelde.

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Die aanspreek van die verwoestyningsprobleem in Suid-Afrika vereis die restourasie van gedegradeerde land, veral gedegradeerde weiveld. Behandelde (bestrykte) en onbehandelde saad van vier smaaklike, meerjarige grasspesies en een semi-meerjarige grasspesie is breedwerpig in gedeeltes van gedegradeerde weivelde ingesaaï na 'n tandploegbewerking. Verskillende grasmengsels en verhoudings is gebruik. Kwantitatiewe inligting vir die sukses van die restourasie metodes, asook die volhoubaarheid en verandering van die ingesaaide gras populasies oor tyd is vasgestel vir vier verskillende studiegebiede (Tweefontein, Totiuskraal, Kromspruit en Davidskatnagel) gedurende 1995 tot 1999 en 1995 tot 2000 vir Totiuskraal. Die samestelling van die grondsaadbank van elke studiegebied vir die somer (1998) is ook vasgestel as 'n aanduiding van die verteenwoordiging van die ingesaaide grasse in die saadbank en om die volhoubaarheid van die gemeenskap te monitor. Die kwantitatiewe data is in die vorm van frekwensie- en digtheidsopnames ingesamel. Digtheidsdata is onderverdeel in die aantal saailinge, vegetatiewe en reprodktiewe groei stadiums van elke grasspesie per een vierkante meter. Saadontkieming is bepaal. Data analise sluit die analise van variansie (STATISTICA²), meervoudige veranderlike analise (DECORANA, Hill, 1979) en die gebruik van ISPD (Geïntegreerde Sisteem vir Plantdinamika, Bosch *et al.*, 1992) in.

In al die studiegebiede het die onbehandelde saad die hoogste ontkieming in die laboratorium gehad, maar die bestrykte saad het die hoogste saailingoorlewing onder natuurlike toestande in die veld gehad, behalwe *Chloris gayana* by die Tweefontein studiegebied.

Die omgewings-, klimaats- en bestuurstoestande by elke studiegebied het spesifieke grasmengsels na die afloop van een jaar bevoordeel. *C. gayana* (onbehandelde saad), *Anthephora pubescens* (bestrykte saad), *Digitaria eriantha* (bestrykte saad) en *Panicum maximum* (bestrykte saad) blyk na een jaar geskik

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te wees vir die 25% sandkleileemgrond van die Tweefontein studiegebied met sy gemiddelde korttermyn reënval van 596 mm/jr gedurende die studietydperk (1995-1999).

- *C. gayana* tree as 'n pleegplant op omdat die gras geërodeerde grond stabiliseer en sodoende ander meerjarige grasse help vestig. Slegs *D. eriantha* en *C. gayana* het volhoubare bevolkings in die eerste seisoen na die toepassing van die restorasie tegniek gevorm. Hierdie twee spesies het grondstabiliteit in die eerste twee jaar na die toepassing van die tegniek voorsien en het ook bygedra tot verbeterde omgewingstoestande vir *A. pubescens* en *P. maximum*.
- Die 29% klei van die Totiuskraal studiegebied naby Potchefstroom se sandkleileemgrond saam met die gemiddelde korttermyn reënval van 773 mm/jr was voordelig vir 'n grasmengsel van *Cenchrus ciliaris* en *A. pubescens* (onbehandelde saad).
- *P. maximum* en *C. ciliaris* is geskik vir die 23% sandkleileemgrond en 517 mm/jr (korttermyn gemiddeld) van Kromspruit.
- Davidskatnagel se 29% sandkleileemgrond en 310 mm/jr gemiddelde korttermyn reënval bevoordeel 'n grasmengsel van *D. eriantha* en *P. maximum* afkomstig van bestrykte saad.
- Die frekwensie van die ingesaaide grasspesies by Tweefontein, behalwe die frekwensies van *D. eriantha* en *A. pubescens* (onbehandeld) het afgeneem. Die digtheid van *D. eriantha* het toegeneem, die ander spesies het afgeneem.
- By die studiegebied Totiuskraal het die digtheid van *A. pubescens* (behandeld en onbehandeld) toegeneem oor die vyf jaar, terwyl die frekwensie toegeneem en weer afgeneem het. Die frekwensie van *C. ciliaris* (onbehandeld) het toegeneem en weer afgeneem, terwyl die frekwensie en digtheid van *C. ciliaris* (behandeld) stabiel gebly het.
- Sommige van die grasse se frekwensie by Kromspruit het toegeneem (*D. eriantha* o, *C. gayana* b + 50%, *C. ciliaris* b en *P. maximum* o en b). Die ander verhoudings en behandelings het eers toegeneem en toe afgeneem. Die oorgrote meerderheid van die spesies se digtheid het afgeneem, maar *D. eriantha*, *C. ciliaris* en *P. maximum* het toegeneem.
- Die frekwensies van Davidskatnagel se ingesaaide spesies het afgeneem, behalwe vir *D. eriantha* wat toegeneem het.

Die grasspesierykheid van elke studiegebied het vir die periode 1995 tot 1999 toegeneem met tussen agt en 14 spesies. Hierdie toename sinspeel op 'n

stabiel graskomsgemeenskap met veerkragtigheid ten tye van versteuring.

Daar was beduidende variasie in die saad digtheid van die gronksaadbanke van die verskillende sub-persele, en alhoewel die gronksaadbanke ryk aan saad is, het die ingesaaide saad drie jaar na die restourasie toepassing daarin voorgekom, behalwe dié van *A. pubescens* en *C. ciliaris*.

Die tandploegbepewking by die Tweefontein studiegebied het die frekwensie van *Cymbopogon plurinodis*, *Eragrostis racemosa*, *Aristida congesta*, *Melinis repens* en *Elionurus muticus* negatief beïnvloed. Die frekwensie van *Setaria sphacelata*, *Eragrostis curvula*, *Themeda triandra*, *P. maximum*, *Cynodon dactylon*, *Eragrostis chloromelas* en *C. ciliaris* het as gevolg van die tandploegbepewking toegeneem. Op grond van die edafiese en klimatologiese inligting, en die graskomsgespesies wat deur die tandploegbepewking bevoordeel is, word die volgende spesies vir restourasie doeleindes van gebiede met 25% klei, 'n korttermyn gemiddelde reënval van 783 mm/jr op grond van vyf jaar se data: *S. sphacelata*, *E. curvula*, *T. triandra*, *P. maximum*, *E. chloromelas*, *C. ciliaris*, *D. eriantha* en *A. pubescens*.

Chloris virgata, *Urochloa mosambisensis*, *C. dactylon* en *Brachiaria eruciformis* se frekwensie het afgeneem na die tandploegbepewking by Kromspruit. Die digtheid van sommige spesies het egter toegeneem, bv. *D. eriantha*, *P. maximum*, *Eragrostis rigidior*, *Setaria nigrirostris*, *A. congesta* en *Bothriochloa insculpta*. Soos genoem vir Tweefontein, is bogenoemde spesies geskik vir die spesifieke gebied se edafiese en klimatologiese kenmerke. *D. eriantha*, *P. maximum* en *B. insculpta* kan 'n geskikte saadmengsel vir restourasie wees vir gebiede met soortgelyke omgewingstoestande (p. ii, paragraaf 2).

B. eruciformis, *Sporobolus ioclados*, *C. virgata*, *Urochloa panicoides*, *E. curvula* en *Sporobolus africanus* se frekwensie het afgeneem waar die tandploegbepewking by Davidskatnagel toegepas is. Spesiefrekwensies wat deur die tandploegbepewking toegeneem het, is *A. congesta* en *E. rigidior*, omdat hierdie spesies aangepas is om in versteurde omgewings te groei.

In al die gevalle het die spesiesamestelling en dus die veldtoestand van die studiegebiede verbeter oor die vyf seisoene na die restourasietoepassing. By Tweefontein en Davidskatnagel waar *D. eriantha* ingesaai was het die graskomsgespesies *D. eriantha* dominant geword. In die geval van Totiuskraal egter het *C. ciliaris* en *A. pubescens* die graskomsgespesies gedomineer aan die einde van die studietydperk (2000). Hierdie twee spesies verkies meer sanderige grond soos in die geval van die Totiuskraal studiegebied. By Kromspruit was die

dominante spesies die eenjarige *Cynodon dactylon* en *Chloris virgata*, maar *D. eriantha* was die dominante meerjarige spesie.

Die gevolgtrekking is dat die samestelling van onsmaklike of eenjarige grasgemeenskappe oor 'n kort periode (ongeveer vyf jaar) verbeter kan word deur gebruik te maak van 'n tandploegbewerking tesame met die insaai van meerjarige klimaksgrasspesies.

Sleutelwoorde: *Anthephora pubescens*, *Digitaria eriantha*, *Cenchrus ciliaris*, *Panicum maximum*, *Chloris gayana*, DCA ordinerings, grondbankanalise, tandploegbewerking, plantegroei stadium, volhoubaarheid.

Kakaretso

Tshelang-tota ya mefuta e mengwe ya tlhaga e e dirisitsweng ka paakanyo ya mafulo a semikgwatata a a boetseng kwa morago.

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Go lwantsha molato wa sekakafatso mo Aferika Borwa go lopa paakanyo ya lefatshe le le boetseng kwa morago le mafulo a a boetseng kwa morago. Peo e e bipilweng le peo e e sa bipiwang ya mefuta e mene ya tatso e e monate ya mefuta ya ditlhaga tsa dingwaga le e ngwe ya tlhaga ya mofuta wa semidingwaga e gaseleditswe mo mafulong morago ga go dirisa mokgwa wa temo ya mogoma wa leino. Go dirisitswe mefuta e e farologaneng ya tlhakanyo ya ditlhaga le dikopantsho tse di farologaneng. Kitso ya bokalo ya go bontsha katlego ya mekgwa ya paakanyo mme tshegetso le phetolo ya tlhaga e e gaseditsweng mo nakong e amogetswe mo mafelong a mane a ithuto (Tweefontein, Totiuskraal, Kromspruit le Davidskatnagel) go tswa 1995 go 1999 le 1995 go 2000 kwa Totiuskraal. Popego ya banka ya peo ya lefelo le lengwe le le lengwe la ithuto la selemo (1998) le tlhomamisitswe ka go lebelela boemedi ba peo e e gaseditsweng mo bankeng ya peo le go lebelela tshegetso ya mefuta ya ditlhaga. Data ya bokalo e dirilwe ka kgatiso ya kgabetsakgabetso le ka kgatiso ya phatlhalatso. Data ya phatlhalatso e kgaoganyeditswe jaaka go latela, palo ya dimela, katiso ka dimela le koketso ka go gola ya dikgala tsa mefuta ya ditlhaga mo sekweremetareng se sengwe le se sengwe. Maatla a go gola a peo e dirilwe. Mokololo wa data e balela le tokololo ya phapaano (STATISTICA²), tokololo ya phapaano ya bontsi (DECORANA, Hill, 1979) le tiriso ya ISPD (Integrated System for Plant Dynamics, Bosch, *et al.*, 1992) (Thulaganyo ya Dimela ya Tshelang-tota e e Lotaneng, Bosch, *et al.*, 1992).

Mo mafelong a ithuto peo e e sa bipiwang e bontshitse maatla a go mela a a kwa godimo mo laboratoring mme peo e e bipilweng e ne e na le phologo ya dimela e e kwa godimo mo tikologong ya tlholego, kwa ntle ga *Chloris gayana* kwa lefelong la ithuto la Tweefontein.

Kemo ya tikologo le kemo tlelaemete le kemo ya tsamaiso go lefelo le lengwe le le lengwe la ithuto e ne e siamisetsa ditlhakanyo tse di farologaneng tsa mefuta ya ditlhaga.

- *C. gayana* (peo e e sa bipiwang), *Antheophora pubescens* (e e bipilweng), *Digitaria eriantha* (e e bipilweng) le *Panicum maximum* (e e bipilweng) di ne di siametse mmu wa motlhaba-letsopa-serokwa wa 25% wa lefelo la ithuto la Tweefontein ka pula ya palogare ya lebaka le lekhutswane la 596 mm/ngwaga ka nako ya ithuto (1995-1999). *C. gayana* ke sejwalwa se se alafang ka gore tlhaga e e emisa kgogolego ya mmu mme ka jalo e thusa ditlhaga tse dingwe tsa dingwagangwaga go iphedisa. *D. eriantha* le *C. gayana* ke tsone fela tse di bontshitseng gore di tshegetsa palo ya tsone mo setlheng sa ntlha morago ga go dira tekeniki ya paakanyo. Mefuta e mebedi tlisitse nitamo ya mmu mo dingwageng tse pedi tsa ntlha morago ga tekeniki mme di thusitse go baakanya kemo ya tikologo ya *A. pubescens* le *P. maximum*.
- Letsopa la 29% la kwa Totiuskraal la mmu wa motlhaba-letsopa-serokwa mmogo le pula ya palogare ya lebaka le lekhutswane la 773 mm/ngwaga le ne le siamelela tlhakanyo ya tlhaga ya *Cenchrus ciliaris* en *A. pubescens* (peo e e sa bipiwang).
- *P. maximum* en *C. ciliaris* e ne e siamelela motlhaba-letsopa-serokwa la 23% le 517 mm/ngwaga (palogare ya lebaka le lekhutswane) ya Kromspruit.
- Motlhaba-letsopa-serokwa la Davidskatnagel la 29% le 310 mm/ngwaga ya pula ya palogare ya lebaka le lekhutswane di siamelela tlhakanyo ya tlhaga ya *D. eriantha* en *P. maximum* ya peo e e bipilweng.
- Phatlhalatso ya mefuta ya tlhaga e e gaseditsweng kwa Tweefontein e ne ya fokotsega mme kwa ntle ga phatlhalatso ya *D. eriantha* en *C. ciliaris*.
- Kwa lefelong la ithuto la Totiuskraal phatlhalatso ya *A. pubescens* (e e bipilweng) e oketsegile mo dingwageng tse thlano, mme le ya *A. pubescens* (e e sa bipiwang) le *C. ciliaris* (e e sa bipiwang) e oketsegile.
- Phatlhalatso ya tlhaga e e gaseditsweng kwa Kromspruit e ne ya oketsega.
- Phatlhalatso ya tlhaga e e gaseditsweng kwa Davidskatnagel e ne ya fokotsega, kwa ntle ga *D. eriantha* le *C. ciliaris*, e e oketsegileng.
- Phatlhalatso (dimela ka sekweremetara) ya mefuta yotlhe ya tlhaga yotlhe e e gaseditsweng kwa mafelong otlhe a ithuto e fokotsegile mme kwa Totiuskraal e oketsegile, go tloga 1995 go ya go 1999.

Khumo ya mefutafuta ya ditlhaga ya lefelo le lengwe le le lengwe la ithuto e oketsegile ka palo ya 8 go ya go 14 mo lebakeng la 1995 go ya go 1999. Koketso e e kaela gore go na le nitamo ya ditlhaga ka koketso e e gakalang ka nako ya go tsikinya mmu.

Go ne go na le pharologanyo e e bonagalang mo phatlhalatsong ya peo mo dibankeng tsa peo tsa mmu mo dipolotong tse di farologaneng mme ka gale dibanka tsa peo di humile ka peo, peo e e gaseditsweng morago ga go dira tekeniki ya paakanyo e tlhageletse mo bankeng, fela kwa ntle ga peo ya *A. pubescens* le *C. ciliaris*.

Temo ya mogoma wa leino kwa tikologong ya thuto ya Tweefontein e dirile gore phatlhalatso ya *Cymbopogon plurinodis*, *Eragrostis racemosa*, *Aristida congesta*, *Melinis repens* en *Elionurus muticus* e fokotsege. Phatlhalatso ya *Setaria sphacelata*, *Eragrostis curvula*, *Themeda triandra*, *P. maximum*, *Cynodon dactylon*, *Eragrostis chloromelas* en *C. Ciliaris* e okeditswe ke temo ya mogoma wa leino. Go ya ka kitso ya boswa le ya mebu le kitso ya mefuta ya ditlhaga e e okeditsweng ke temo ya mogoma wa leino go ka tlhagisiwa gore mefuta e e latelang e ka dirisiwa paakanyo ya mafulo mo ditikologong tse di nang le mmu wa mmopa wa 25%, pula ya paka-khutswane ya 783 mm ka ngwaga le pula ya paka-telele ya 491mm ka ngwaga le go ya ka kitso e e kgobokantsitsweng dingwaga di le tlhano. Mefuta ke: *S. sphacelata*, *E. curvula*, *T. triandra*, *P. maximum*, *E. chloromelas*, *C. ciliaris*, *D. eriantha* en *A. pubescens*.

Phatlhalatso ya *Chloris virgata*, *Urochloa mosambisensis*, *C. dactylon* le *Brachiaria eruciformis* e fokotsegile morago ga temo ya mogoma wa leino kwa Kromspruit. Phatlhalatso ya mefuta e mengwe ya tlhaga e ne ya oketsega jaaka *D. eriantha*, *P. maximum*, *Eragrostis rigidior*, *Setaria nigrirostris*, *A. congesta* le *Bothriochloa insculpta*. Jaaka go kaetswe kwa Tweefontein, mefuta e e fa godimo e siametse mmu le tlelaemete ya lefelo le le totobetse. *D. eriantha*, *P. maximum* le *B. insculpta* e ka siamelela tlhakanyo ya paakanyo mo mafelong a maemo a tikologo a a tshwanang.

Phatlhatso ya *B. eruciformis*, *Sporobolus ioclados*, *C. virgata*, *Urochloa panicoides*, *E. curvula* le *Sporobolus africanus* e fokotsegile mo go dirisitsweng temo ya mogoma wa leino kwa Davidskatnagel. Mefutafuta ya ditlhaga e e okeditsweng ke temo ya mogoma wa leino ke *A. congesta* le *E. rigidior* ka gore mefuta e e dirilwe gore e dumele mafelo a a tsikintsweng.

Mo dintlheng tsotlhe mefutafuta ya ditlhaga le kemo ya dinaga mo mafelong a ithuto e oketsegile mo dintlheng tse tlhano morago ga go dira paakanyo. Mo *D. eriantha* e gaseditsweng mo teng mefuta ya ditlhaga ya *D. eriantha* e ne ya nna phekeetsi. Kwa Totiuskraal, *C. ciliaris* le *A. pubescens* e nnile phekeetsi mo

nakong ya bokhutlo ba ithuto (2000). Mefuta e mebedi e e ithatela mmu o o motlhaba jaaka kwa lefelong la ithuto kwa Totiuskraal.

Ka bokhutlo go ka twe tshelang-tota le tswelelopele ya ditlhaga tsa tatso e e seng monate kgotsa tsa ngwaga e ngwe e ka oketswa mo teng ga nako e khutswane (\pm dingwaga tse thlano) ka go dirisa mokgwa wa temo ya mogoma wa leino mmogo le go gasa mefuta ya ditlhaga tsa dingwaga tsa ditlhaga tsa setlhoa.

Mafoko a pulo: *Antheophora pubescens*, *Digitaria eriantha*, *Cenchrus ciliaris*, *Panicum maximum*, *Chloris gayana*, DCA thulaganyo, molokololo wa banka ya peo mo mmung, temo ya mogoma wa leino, dikgala tsa go mela tsa dimedi, tshegetso.

Abstract

The dynamics of certain grass species used during the restoration of degraded semi-arid rangelands.

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Addressing desertification in South Africa requires the restoration of degraded land, particularly degraded pasture. Enhanced (coated) and untreated seed of four palatable, perennial grass species and one semi-perennial grass species were broadcasted into part of degraded pastures following a rip plough cultivation method. Different grass mixtures and ratios were used. Quantitative information for the success of the restoration methods as well as the sustainability and change of the oversown grass population over time was determined in four different study areas (Tweefontein, Totiuskraal, Kromspruit and Davidskatnagel) during 1995 to 1999 and 1995 to 2000 for Totiuskraal. The composition of the soil seedbank of each study area for the summer (1998) was determined as an indication of the representation of the oversown grasses in the seedbank and to monitor the sustainability of the community. The quantitative data were in the format of frequency and density surveys. Density data was subdivided in the number of seedlings, vegetative and reproductive growth stages of each grass species per square meter. Seed viability was determined. Data analysis included the analysis of variance (STATISTICA²), multi variate analysis (DECORANA; Hill, 1979) and the use of ISPD (Integrated System for Plant Dynamics; Bosch *et al.*, 1992).

In all the study areas the untreated seed had the highest germination rate in the laboratory, but the enhanced seed had the highest seedling survival rate under natural conditions in the field, except *Chloris gayana* at the Tweefontein study area.

The environmental, climatological and managerial conditions favoured specific grass mixtures at each study area at the end of the first year.

- *C. gayana* (untreated seed), *Anthehora pubescens* (enhanced seed), *Digitaria eriantha* (enhanced seed) and *Panicum maximum* (enhanced seed) were appropriate after one year for the 25% sandy-clay-loam sand of the Tweefontein study area with its average short-term rainfall of 596 mm/yr. (1995 - 1999). *C. gayana* is a nursing plant because it stabilizes the eroding

soil and thus contribute to the establishment of other perennial species. Only *D. eriantha* and *C. gayana* formed sustainable populations in the first season after the application of the restoration technique. These two species provided soil stability in the first two years of the application and contributed to improved environmental conditions for *A. pubescens* and *P. maximum*.

- The 29% clay of the Totiuskraal study area near Potchefstroom combined with the average short-term rainfall of 773 mm/yr. was ideal for a grass mixture of *C. ciliaris* and *A. pubescens* (untreated seed).
- *P. maximum* and *C. ciliaris* were suited for the 23% sandy-clay-loam soil and 517 mm/yr. (short-term average) of Kromspruit.
- Davidskatnagel's 29% sandy-clay-loam soil and 316 mm/yr. average short-term rainfall favoured a *D. eriantha* and *P. maximum* enhanced grass mixture.

- The frequency of the oversown grass species at Tweefontein, except for the frequencies of *D. eriantha* decreased. The density of *D. eriantha* increased, but the other species decreased.
- At the Totiuskraal study area the density of *A. pubescens* (enhanced) increased over a five-year period. *A. pubescens's* (u) frequency at first increased and then decreased. The frequency and density of *C. ciliaris* (untreated) first increased as well, and then decreased, while the frequency and density of *C. ciliaris* (u) stabilised.
- Some of the species at Kromspruit increased in frequency (*D. eri* u, *C. gay* e + 50%, etc.). The other ratios and treatments first increased and then decreased. The overall number of species increased in density, except *D. eriantha*, *C. ciliaris* and *P. maximum*.
- The frequencies of the Davidskatnagel's oversown species decreased, except for *D. eriantha*, which increased.

The grass species richness of each study area increased for the period 1995 to 1999 with between eight and 14 species. This increase hints at a more stable and resilient grass community.

There was significant variation in the seed densities of the soil seedbanks of the different sub-plots, and although the soil seedbanks are rich in seed, none of the oversown seed appeared in the soil seedbanks three years after the restoration application, except for *A. pubescens* and *C. ciliaris*.

The rip plough cultivation method at the Tweefontein study area influenced the frequencies of *C. plurinodis*, *Eragrostis racemosa*, *Aristida congesta*, *Melinis repens* and *Elionurus muticus* negatively. The frequencies of *Setaria sphacelata*, *Eragrostis curvula*, *Themeda triandra*, *P. maximum*, *Cynodon dactylon*, *Eragrostis chloromelas* and *C. ciliaris* increased because of the rip plough cultivation method. Based on the edaphic and climatological information and the grass species favoured through the rip plough cultivation method, the following species are recommended for restoration purposes: *S. sphacelata*, *E. curvula*, *T. triandra*, *P. maximum*, *E. chloromelas*, *C. ciliaris*, *D. eriantha* and *A. pubescens*.

Chloris virgata, *Urochloa mosambicensis*, *C. dactylon* and *Brachiaria eruciformis*'s frequencies decreased after the rip plough cultivation method at Kromspruit. The density of some species, however, increased, e.g. *D. eriantha*, *P. maximum*, *Eragrostis rigidior*, *Setaria nigrirostris*, *Aristida congesta* and *Bothriochloa insculpta*. As mentioned for Tweefontein, the above mentioned species were suitable for the edaphic and climatological characteristics of the specific area. *D. eriantha*, *P. maximum* and *B. insculpta* could be an appropriate seed mixture for restoration in areas of similar environmental conditions (p. ii, paragraph 2).

B. eruciformis, *Setaria iocladis*, *C. virgata*, *E. curvula* and *Sporobolus africanus*'s frequencies decreased where the rip plough cultivation method was applied at Davidskatnagel. Species frequencies that increased due to the rip plough cultivation method (i.e. species adapted to disturbance), was *A. congesta* and *E. rigidior*.

In all the cases the species composition and thus the field condition of the study areas improved over the five seasons after the restoration application. At Tweefontein and Davidskatnagel where *D. eriantha* was oversown, the grass communities became *D. eriantha* dominant. In the case of Totiuskraal, though *C. ciliaris* and *A. pubescens* dominated the grass community at the end of the study period (2000). The latter two species prefer more sandy soil as is the case for Totiuskraal. At Kromspruit the dominant species were the annuals *C. dactylon* and *C. virgata*, but the perennial grass that became dominant was *D. eriantha*.

In conclusion, the composition of unpalatable or annual grass communities can improve over a short period (approximately five years) through the combined use of rip plough cultivation method and oversowing of perennial climax grass species.

Keywords: *Anthephora pubescens*, *Digitaria eriantha*, *Cenchrus ciliaris*, *Panicum maximum*, *Chloris gayana*, DCA ordination, soil seedbank analysis, rip plough cultivation methods, life growth stage, sustainability

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Chapter 1. Introduction

1.1 Degradation – the problem and extent thereof

Land is the resource for home construction, industry and infrastructure, crop production, recreation, conservation and genetic biodiversity, as well as the source of water, minerals and energy. Humans use land to store water and to dispose of waste materials. The growing populations of today's society blame desertification or dryland degradation, caused by human activities, as the underminer of a secure environment, food security, financial security and preferred livelihoods (Dean *et al.*, 1995; Badenhorst, 1996; Harris *et al.*, 1996; Hoffman *et al.*, 1999). The causes of degradation are also said to be climatic variability linked with human activities (Squires, 1994; Rogers, 1996). These human activities usually include poor agricultural practices (uncontrolled debushing, inappropriate type of cultivation, overstocking and irrigation), salinisation, soil compaction, species encroachment due to overgrazing and mining activities (Dregne, 1995; Zimmer, 1995; Haro *et al.*, 1996). Degradation occurs in surface water resources, groundwater resources, soil and vegetation (Hoffman *et al.*, 1999). Vegetation degradation includes poor veld condition, bush encroachment, alien plants, deforestation, and veld clearing for either crop production and/or settlements. This project focused on the poor veld condition aspect of vegetation degradation.

Some authors mentioned another cause of degradation, namely the shift of paradigms towards the pastoral system. Land use changed from nomadism towards settled pastoralism with its ensuing social and political developments. The latter had been perceived as a maladaptive and destructive system of exploitation, but recently the blame for land degradation has been laid at the door of structural institutions (Ellis & Swift, 1988; Du Pisani *et al.*, 1998). Ellis and Swift (1988) stated that years of intervention into pastoral systems had failed to relieve the perceived problems, sometimes rendering the target population and its ecosystem more degraded than before intervention, and therefore coined pastoralism as a maladaptive and destructive system. Degradation usually results in one of the following:

- 1) loss of the productivity of the specific area (Botha, 1996; Kellner, 2000),
- 2) decrease in the available natural resources (Sefe *et al.*, 1996),

- 3) decrease in biodiversity (coupled with the loss of genetic variation) of an area (Tilman *et al.*, 1996),
- 4) wind and water erosion (Dregne, 1995),
- 5) unpalatable field composition (Walker, 1988) with subsequent loss in animal production,
- 6) unsuitable conditions for seedling establishment and survival (Dean *et al.*, 1995),
- 7) introduction of invasive aliens which out-compete indigenous plant species and
- 8) increase in termite populations.

The term, degraded land, has already been used to denote land damaged in some way by human activities. Other terms such as despoiled, disturbed, devastated, derelict, disused, damaged, contaminated, and polluted are also used and interchanged often without precise definitions being made. Some words are used in specific countries and by specialist groups and are not widely understood. Distinction can be made between terms describing the problem and those describing the solution. Terms used to describe the means of dealing with degradation are often confused; for example words such as restoration, reclamation, rehabilitation, remediation and amelioration (Harris *et al.*, 1996). These are discussed in paragraphs 1.2 and 2.1 of this dissertation.

Terms describing the problem of degradation are the following, according to Harris *et al.* (1996):

- Disturbance:** This is any event which causes a sudden change in the nutrient status of the system in either a destructive or an enriching way leading to changes in the size of the standing crop and its species composition.
- Stress:** Any environmental factor that prevents the accumulation of additional biomass.
- Degradation:** The combination of processes which leads to the land under consideration no longer being fit for a wide range of uses; from natural systems to building sites. Whenever a self-sustaining system is the end-use, such land will require remedial action.
- Derelict land:** Land so damaged by industrial or other development that it is incapable of beneficial use without treatment.

Contaminated land: Land that contains substances that, when present in sufficient quantities or concentrations, are likely to cause harm directly or indirectly to humans, the environment or other targets such as construction materials.

Several types and sources of land disturbance and dereliction exist. Much damage results from inefficient use or overuse of resources or lack of understanding of ecosystem function, but sometimes the damage results from wilful negligence. Some degradation is regulated on a temporary basis (e.g. quarries, strip/open-cast mines, civil engineering or landfilling) or a permanent basis (agro-forestry, civil engineering, built structures and economic decline). In other cases there are ecosystem depletion through uncontrolled recreation, wildlife hunting, poaching, theft of genetic resources or pollution (Harris *et al.*, 1996). The above-mentioned knowledge regarding degradation and desertification was generated in the last thirteen years as an outcome of the Plan of Action to Combat Desertification drawn up in 1987 at the 10th United Nations Conference on Desertification. As part of the Action Plan, the extent of desertification in the world and in South Africa was determined (Kassas, 1987; Hoffman *et al.*, 1999).

A total of 30% of the land area of the world is affected by desertification, including 73% of the drylands of Africa. Nearly 91% of South Africa is arid (receives less than 300 mm/yr), semi-arid (receives between 300 and 600 mm/yr) or dry sub-humid and broadly falls within the United Nations Committee of Combating Desertification (UNCCD) definition of "affected drylands". These are countries where the ratio of annual rainfall to potential evapotranspiration is between 0.05 and 0.65, as is the case in the arid and semi-arid areas of South Africa. Communal areas cover less than 14% of South Africa's surface area. In the North West Province of South Africa there is a considerable mixing of communal and commercial land tenure systems. The shrinking of grazing lands is almost 3 times higher in communal areas than in commercial areas. 57% of the North West Province is arid and 43% is semi-arid. The areas used for settlement are steadily increasing over the whole of the North West Province, and with this increase, the demand placed on the natural resources also increases (Hoffman *et al.*, 1999).

Rogers (1996) stated that, until recently, attention had been focused on the preservation of areas not occupied by other land uses and not severely affected by human exploitation. However, as human populations expand, primary habitats

disappear and increasing pressure is placed on the scattered remnants. Restoration now appears a viable, if not the only option left for concerned environmentalists. The economical and ecological costs due to the degradation of the land's natural resources, as well as the attempts to better and replenish these resources, already amount to hundreds of thousands of dollars yearly (De Villiers, 1994; Choi & Wali, 1999).

1.2 Restoration ecology

Several solutions exist to the problem of degradation and these are described by different terms. Restoration ecology is more than just a solution, however, to degradation. A broader perspective on restoration ecology is given in Chapter 2, section 2.1. This section, though, examines some of the terms used to describe the solutions found in restoration ecology.

Reclamation: a process by which previously unusable land is returned to a state whereby some use may be made of it (Harris *et al.*, 1996), e.g. cultivation or to bring it back to a proper state (Bradshaw, 1966). This is the first stage of restoration and includes land gained from submerged coastal lands, desert or wetland areas. Tainton (1981) confirms the definition of reclamation.

Rehabilitation: applies to areas that formerly had no plant growth at all, but with careful fertilisation and landscaping works may be used to grow a limited number of plant species (Harris *et al.*, 1996). Bradshaw (1990) defines rehabilitation as a restoration effort that was not completely successful. In his 1984 article Bradshaw unravels rehabilitation to the action of restoring a thing to a previous condition or status. The latter definition has little or no implication of perfection and may indicate any act of improvement applied to a degraded area.

Restoration: the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems. The process by which an area is returned to its perfect original state prior to degradation of any sort, i.e. back to a fully-functioning self-sustaining ecosystem. Exotic species can be considered for restoration purposes in some circumstances

(Jordan *et al.*, 1990; Harris *et al.*, 1996; Rogers, 1996). This return of natural plant communities occurs along the set of succession regulations (i.e. nudation, migration, ecesis) (MacMahon, 1990). Turner (1990) adds an interesting perspective to the definition, viz. creating beauty or something that provides aesthetic pleasure, while McNeilly (1990) place the focus the preservation of the integrity of naturally evolved populations. Tainton (1981) defined restoration as man's activities (i.e. artificial processes) to halt and/or reverse the process of deterioration with the eventual objective of returning the vegetation to an original state. The techniques used usually include soil disturbance, seeding and/or fertilisation. Bradshaw (1966 and 1990) is the only author other than Harris *et al.*, (1996) that endeavoured to distinguish between different words used in restoration ecology. He broadly defines restoration as the process of controlling at will (e.g. decelerating, accelerating, reversing, altering, steering or even entirely preventing the change in the vegetation composition of a restored area. Trimming the focus, though, he states that restoration is an item for item reproduction of the system, artificially overcoming the factors that ecologists consider will restrict ecosystem development.

Renovation: was defined by Tainton (1981) as the re-establishment of vegetation of good structure and vigour; as near as possible to the original condition, irrespective of whether the starting point was bare or vegetated soil.

Replacement: in which an alternative to the original ecosystem is produced, which could be less diverse, but more or less productive (Bradshaw, 1990) He later added the concepts 'substitute or equivalent to the original ecosystem' to the definition.

Remediation: the act of remedying, i.e. to rectify, to make good. The emphasis is on the process and not so much on the end use (Bradshaw, 1966).

The ideal for restoration is pro-active behaviour (precaution), rather than dealing with problems arising from unplanned actions. Under the precautionary principle,

four points are worth mentioning, i.e. 1) act now, rather than too late, 2) do not mine/use resources to their limits of exhaustion, 3) delegate management to several managerial levels, and 4) the developer should deliver proof of the achievements (Harris *et al.*, 1996).

Restoration aims at the sustainable use of land as a resource. Sustainable use of land is achieved by keeping the land in good condition through supplying the physical, chemical and biological inputs required for the land's long-term maintenance. Sustainable use of land can only be achieved if that land-use is properly assessed. For this assessment an understanding of the functioning of terrestrial ecosystems and their development is necessary (Squires, 1994; Harris *et al.*, 1996; Selman, 1996). Functional knowledge assures restoration that works. Thus, the interaction between an ecosystem's geology, soil characteristics, vegetation, animal life and atmosphere should be taken in consideration. Under the heading geology and soil, the important aspects to remember are biogeochemistry, soil weathering, soil composition and nutrient availability. An important task of any restoration programme will be to alter substrate conditions to benefit plant growth, keeping in mind that substrate alterations must be able to sustain systems in flux (Harris *et al.*, 1996).

The vegetation aspect of an ecosystem includes the photoautotrophs, carrying capacity, the importance of biodiversity and the hypothesis of order and chaos. Where nutrient cycling has been influenced, the influence will have to be addressed, because specific plants have specific nutrient requirements (Harris *et al.*, 1996). When selecting plant species for rehabilitation, aspects to consider are the availability of plant or seed material, possible propagation and germination problems, the desired future use of the site and the ecological stability of the candidate species (Theunissen, 1993; Squires, 1994; Kellner & Jordaan, 1996).

The end-uses of a restoration site need to be kept in mind as well. Soft end-uses are goals, in which the area is covered by vegetation of some sort, for example, public parks, while for hard end-uses, the area is characterised by buildings, etc. The history of degradation of an area will determine the route back to self-sustainability. There is a sequence of events that should, ideally, be followed when a change in land-use is planned or occurs as a result of external factors. The following discussion states the procedure for damage assessment and reparation strategies, following this sequence. Assessment strategies include the definition of environmental quality; namely, a resource is an attribute of the

environment appraised by man to be of value over time within constraints imposed by the social, political and institutional framework. When assessing resources, the scale of a project should be kept in mind, as well as the type of information needed (Van Wyk, 1994; Harris *et al.*, 1996).

Restoration of reclaimed land starts with preparing the substrate for growth and reclamation to agro-forestry uses. The substrate handling and re-instatement procedures of the subsoil should be decided upon prior to the restoration process. The characteristics of materials serving as substrates for plant growth on the degraded sites should be kept in mind. At industrial sites, rubble or fill material is the substrate, which fall outside the scope of this study. Other soil characteristics to consider are the pH, toxicity, lack of nutrients and organic matter, the particle size distribution and the compaction of the soil. Certain treatments should be considered to overcome constraints for the establishment of vegetation (e.g. covering system, contamination, etc). Where drainage is required a decision should be made between surface drains and ditches or under-drainage. The role of vegetation in reclamation and restoration is very important. Vegetation serves as a nutrient source because it cycles nutrients in the ecosystem and provides organic matter. Vegetation provides cover, leading to improved soil structure and shelter for other species (Barbour *et al.*, 1987). Vegetation can fulfil an engineering function by supplying mechanical and hydrological support, assist in decontamination and provide an esthetical visual impact (Harris *et al.*, 1996).

Agricultural restoration of previously cultivated areas includes the disruption of compacted horizons and aggregate structure improvement (Davies *et al.*, 1986). The financial and mechanical limitations laid upon landowners or users dictate the extent to which restoration on agricultural land occurs. Again, field drainage should be installed where necessary and field water supplied through troughs. Access to the area should be constructed and wood and shelter belts on exposed ridges and hills erected. Non-agricultural features, such as wildlife areas, species-rich meadows, wetlands, public access and amenity use can be added. Agricultural restoration such as the establishment of a grass cover against erosion and the improvement of soil structure and managed grazing should be implemented. Fertiliser and organic inputs should be in accordance with the management of soil structure. The encouragement of soil biological communities and the introduction of microbial communities can both lead to stability and diversity (Harris *et al.*, 1996).

The establishment, management and maintenance of self-sustaining vegetation will be based on the land-use selection criteria because this criteria will dictate the restoration process. Natural vegetation of degraded land usually follows one of the following succession modes: facilitation, tolerance, inhibition or random establishment. When plants are introduced, the vegetation types suited for the area should be clarified. In areas used for nature conservation, the existing natural condition value should be estimated and reclamation to increase wildlife value implemented. Soil development in naturally vegetated sites and restored sites differs and should be kept in mind in the restoration process (Jenny, 1983). In moving from agro-forestry to self-sustaining systems one must realize that nutrients in the agro-forestry systems are reduced, a lower biological potential exists, the hydrology needs to be addressed and the substrate may differ. In agro-forestry there is a lack of cover, several barriers are present and the soil is highly erodable. The system also lacks resilience to variability of stress and disturbance (Begon *et al.*, 1990). The managing and after-use phase will greatly benefit from setting objectives, deciding strategy, implementing action plans and monitoring the process with fine tuning (Harris *et al.*, 1996).

Restoration may fail for several reasons. First of all, restoration may not be successful due to failure to implement all aspects of the restoration plan as a consequence of inadequate site surveys. The ecology of the system is therefore inadequately understood. Furthermore, the vegetation may regress because of various factors (decline in pH, lack of nutrient cycling, etc.). Solutions in treating these failures are easily found in the interdisciplinary approach and by the impartation of the sense of ownership to the other parties involved. Certain priorities remain for research, legislation, educators and activists (Harris *et al.*, 1996).

The economic implications of rangeland restoration can be a cause of great concern to most farmers, however, and it is therefore important to look at the most inexpensive, but still effective practice to improve the degraded pasture. Rangeland restoration can be regarded as a long term investment, but is to a large extent dependent on natural conditions, including climatic conditions (Milton & Dean, 1995; Van der Merwe, 1997).

The role that restoration can and should play in resolving conflicts between economic growth and environmental protection remains controversial. Rogers (1996) asked how far development should be allowed with resulting

environmental sacrifices. Clearly the line between progress, land-use planning and environmental sacrifice, is at best fine. The only worldly way to address degradation is through sustainable development – development that seeks the improvement of the quality of human life while living within the carrying capacity of the supporting ecosystems (Rogers, 1996). Rogers's (1996) approach is all together humanistic towards the problem of degradation. The humanistic approach does not address the spiritual decay of the people at all, and lays a very shaky foundation for future generations.

1.3 The use of dynamic studies of grass species during the restoration of degraded semi-arid rangelands

The ideal natural pasture has a high productivity of palatable species and a diversity of summer as well as winter grasses, enabling stock to feed the whole year round. The dynamics of well-managed pastures are thought to meet these demands in that the different species exist in equilibrium with one another. The description of these changes in either the species (autecology), the population (demography) or the community (synecology) is collectively called vegetation dynamics (Odum, 1913; Barbour *et al.*, 1987; Allen *et al.*, 1995). According to Clements's theory, the driving forces behind equilibrium dynamics are competition and 'biotic reaction' (Barbour *et al.*, 1987). This theory insufficiently explains the dynamics of all systems and in particular those of the semi-arid rangelands with unpredictable environments. For the latter, demographic studies are more appropriate. Demographic studies can be divided into two types:

- 1) Those studies focusing on the successful establishment of new plants as an uncommon event. The establishment event depends on the right combination of available propagules, current climatic conditions and the presence and/or absence of fire and/or herbivores. Once established, the propagules demonstrate typical cohort survivorship curves. Theoretically, a cohort is all the seedlings that germinated at a particular time (Barbour *et al.*, 1987), i.e. seedlings of the same age (Lawrence, 1989). In practice, though, a cohort is the amount of same aged seedlings that survive from one time of measurement to the next. Mortality may be influenced by plant condition, which in turn may be influenced by available moisture, fire and grazing.

- 2) The second type of studies are those dealing with shorter time scales and semi-arid rangelands. They highlight the importance of different plant growth forms that respond differently to different weather conditions. Management must therefore concentrate on improving the establishment of desirable species, based on the knowledge of which growth forms and species will be favoured by particular climatic conditions (Kellner & Jordaan, 1996).

Detailed autecological studies of the rangeland species improve management strategies. This enables us to identify the times when management could successfully intervene and influence the dynamics of the sward in the desired direction (Walker, 1980; Shackleton, 1991; Theunissen, 1993).

As part of a community, every plant in an ecosystem has a specific role to fulfil. Removing or disturbing the plant(s) could cause an imbalance in the systems' productivity and self-sustainability (Barbour *et al.*, 1987; Harris *et al.*, 1996; Rogers, 1996; Richardson, 1997). Studies on the autecology and plant-environment relationships of the species enlightens their full potential as restorative agents and also attributes to the preservation of the species (Archer & Pyke, 1991; Harris *et al.*, 1996).

In determining the sustainability of a grass population, as this study did, the turnover rate between the different life growth stages of a plant species needs consideration (Kellner & Jordaan, 1996).

The scope of population dynamics is extremely broad. Terms describing population dynamics include turnover rate, variation at the tiller and seed levels (O'Connor & Everson, 1998) or the presence or absence of a specific species (persistence of a species). Turnover rate is the change of species/part thereof in a given space for a given period of time, (Hodgson & Illius, 1996; Kellner & Jordaan, 1996; Morgan, 1998). Other concepts are the cumulative frequency of a given species that give an indication of a species mobility. Population dynamics include species richness and can be described as a community having a given stability (Begon *et al.*, 1990).

Population dynamics are concerned with the recruitment and death of plants, density being the accumulated net result of these processes. Pastures are considered stable when the same basic botanical composition is maintained.

Unstable pastures will not maintain the same botanical composition and this instability can be desirable or not. For example, introduction of legumes and application of nutrients to nutrient limited soil or the replacement of some unproductive species by more agronomically desirable species may be more desirable to a specific land-user (Jones & Mott, 1980). Instability is undesirable where agronomically useful species are eliminated concurrently with the invasion of less productive or unpalatable species (Roberts, 1972). In unstable pastures, population dynamics are easy to visualise, since changes in species composition clearly reflect the recruitment, survival and death of the individuals involved. The same events occur in stable pastures, even though they are more easily overlooked in perennial fields (Jones & Mott, 1980). Data originating from the field dynamic studies are usually incorporated in models. As the vegetation composition changes over time, the vegetation condition of the particular study area also changes, resulting in the study area to occupying a different position within the model.

There are several paradigms on which scientists base their understanding and management plans of rangelands. The succession concept is the foundation for most of these paradigms. Clements (as quoted by Jordaan, 1997) described succession as the process where the present plant species in a habitat change that habitat to one more suitable for other plant species. The plant species therefore succeed one another, until a community composition is reached where the species do not have that dramatic influence on the habitat anymore. The latter community does not change in composition unless a disturbing influence from outside creates open spaces. The succession process starts all over in that opened space. A community that does not change in composition (i.e. is stable) is known as a climax community. The concept of succession gave rise to what is called the Range Succession model (Westoby *et al.*, 1989), i.e. a given range (pasture) has an optimum condition (climax) in the absence of grazing. Succession towards this climax is a steady process. Grazing pressure produces changes that are also progressive and are in the opposite direction to the succession tendency, e.g. heavy overgrazing steers a plant community towards erosion and bare patches. This model is also called the Standard Range Succession-Regression model (Dodd, 1994). The model argued that the climax condition was retained when the pasture was grazed at a particular grazing capacity, but the Range Succession model negated the influence of rainfall and fire. Further criticisms against the Range Succession model included the use of under-utilised pastures as benchmarks, the climax system is not the best for

livestock production and lower grazing capacities lead to bush encroachment rather than returning to the climax system (Jordaan, 1997). Realising that the Range Succession model insufficiently described the changes occurring in pastures, a significant shift of paradigm occurred at the hands of Westoby *et al.* (1989). He stated the vegetation of a pasture (field) has a specific composition (condition). The vegetation condition (state) differs between vegetation units or future field composition due to available ungerminated seed in the soil. The dynamics in each state is complex and can be presented as a series of transitions. Natural causes and/or management practices (e.g. large changes in weather, intense grazing pressure and/or fire) trigger the transitions between states (Westoby *et al.*, 1989). They called the model the State and Transition model. The State and Transition model was far more accurate in its description of the changes in vegetation composition and the factors influencing these changes, but again the State and Transition model did not explain the inability of certain states to return to former states. Friedel (as quoted by Dodd, 1994) then added the idea of thresholds to the State and Transition model. Thresholds are phenomena that essentially inhibit transition between different relatively stable states of rangeland ecosystems, because they are limits of resiliency i.e. spatial and temporal boundaries between two states. Once a state moves beyond its limit, return to the previous state can only be achieved through intervention (Jordaan, 1997). The Non-equilibrial Persistent model of Ellis and Swift (as quoted by Dodd, 1994) assumes as does the Threshold and State model, that the dynamics of communities are equilibrial, but in arid rangelands in Kenya the community dynamics are non-equilibrial. The ecosystems do not usually respond to grazing pressure, but instead are almost completely regulated by abiotic controls.

Repeated measurements in small plots in grasslands reveal that the composition and structure of grasslands are highly dynamic in space and time. The rate and extent of a species' dynamics are influenced directly by many factors, including:

- 1) the individualistic species responses,
- 2) environmental factors, including environmental fluctuations and overriding climatic conditions; and
- 3) management of disturbances, and changes to the disturbance regime, which may cause rapid changes in small-scale plant dynamics (Morgan, 1998).

Vegetation of semi-arid areas world-wide that is managed for pastoral use, has been shown to be inherently unstable, resulting in marked year-to-year fluctuation in species composition. The instability may be exacerbated by a

tendency for vegetation to change from one state to another of a range of several alternative states (Westoby *et al.*, 1989) according to the vegetation composition present at the time of measurement. Grazing usually controls the switches between alternative states. This instability in the semi-arid areas causes concern about soil and vegetation degradation under pastoral management.

Demographic studies do not explain the mechanisms controlling population dynamics. For such answers, deliberate manipulation of potential control factors is required (Meyer & Schmid, 1999). These do not fall within the scope of this study.

Variation in annual rainfall causes changes in the abundance of individual species and these changes are also driven by maximum drought events. The abundance of a species may wax or wane in response to rainfall variability. The consistent effect of grazing is small on an annual basis but cumulatively large over time (O'Connor & Everson, 1998).

The cover of tall species, reducing light penetration to lower layers of the grassland and restricting the development of shorter species, increases quickly without regular grazing or mowing. The dominance of tall grasses and the non-removal of organic matter also lead to the formation of a thick litter layer, which hinders germination and the growth of seedlings and runners. Grass seeds have a short life span in the soil (Bakker *et al.*, 1996) and poor dispersal ability. Development of grasslands slowly proceeds from abandoned fields. Therefore, the maintenance of existing communities seems to be easier than the restoration of former grasslands.

1.3.1 Grass population dynamic parameters

Population dynamics are described by several parameters:

- 1) density (the number of individuals per unit area, Brown, 1957; Falinska, 1991),
- 2) net primary productivity (NPP) = change in weight over time (g/t), t/ha/yr (Pearson & Ison, 1989),
- 3) biomass estimates (Pieper, 1988), which use the direct harvest method, cutting the vegetation as close as possible to the soil surface or at the height that a particular animal utilises the vegetation under consideration. The data is noted as weight per unit area. From these data, the carrying

- capacity (the initial starting points for basic stocking plans, range condition and dominance of certain species) can be estimated as well as the relative role or importance that a species fulfils in the plant community,
- 4) frequency (the dispersion or distribution of species in a plant community) expresses the homogeneity or heterogeneity of the community (Brown, 1957),
 - 5) abundance (the number of individuals of a particular species) and percentage composition (the number of individuals of a species expressed as a percentage of all the individuals of all the species) are also useful parameters of population dynamics.

The parameters used in this study are density, frequency and the structure of the soil seed banks. The density for most of the study areas is divided into the number of seedlings, vegetative and reproductive plants, as an indication of the sustainability of the particular species (Brown, 1957).

Another way of measuring sustainability is to follow the recruitment, growth and death of plant genets through time and space (Kellner, 1995, Fair *et al.*, 1999). Such measurements require long-term monitoring of individual plants or populations as a whole as is the case in this study (Fair *et al.*, 1999). Although grasslands have a general uniformity in structure, considerable variation exists in their population dynamics at tiller and seed levels (O'Connor & Everson, 1998). The relative importance of ramets and genets depends on the environment of the plant. In savanna there is a continual turnover of tufts, mostly as a result of drought-induced mortality. Persistence of the population is therefore dependent on seedling recruitment. That is why one of this study's focus points is seedling survival. Savanna grasses are predominantly perennial with the proportion of annuals increasing with aridity, as is well seen in the North West Province of South Africa. Species attributes influence their spatial and temporal patterns of community change in response to variability in rainfall, grazing and fire. Seed production of savanna species depends on the amount and seasonal distribution of rainfall (Baskin & Baskin, 1998).

The attention is now turned entirely towards this particular study, its origin, aims and the format of this dissertation.

1.4 Origin of project and community involvement

In 1995, Dr. K. Kellner started a project in co-operation with the National Department of Agriculture: Directorate Resource Conservation¹ (Restoration ecology of degraded rangelands, no. 6/1/1/3/3-85/98). The main objectives of the 'restoration of degraded rangelands' include:

- 1) Evaluation of existing restoration technologies in order to construct a Decision Support System (data base and expert system) for restoration ecology in South Africa. This includes the incorporation of the data into the WOCAT (World Overview of Conservation Approaches and Technologies) data base and presenting the data and results by means of a Web Site which is coupled to the Web Site of the National Department of Agriculture.
- 2) Setting up of national restoration demonstration sites of one to three hectares in size in degraded areas in SA. Ten sites have been selected that will be managed by a collaborator as appointed by the project leader, Dr. Kellner. Demonstration sites will have to be established by the land users in that region by a participatory, community type approach. At each of the demonstration sites, a number of restoration technologies that have been identified by the land users will be researched. Restoration technologies will include mechanical and/or biological methods, with or without re-seeding treatments.
- 3) Evaluation of the most appropriate seed types for restoration ecology that can be used in the re-seeding trials, and that are adapted to the different environments where the demonstration sites will be established, part of which is dealt with in this study.
- 4) Setting up an awareness, training and implementation strategy for restoration ecology for researchers, extension workers, land users, community members and learners in the different regions.
- 5) Supplying the Department of Agriculture with guidelines and advice to formulate future policy about Nature Conservation and in particular restoration ecology.

¹ ☒ National Department of Agriculture: Directorate Resource Conservation, Private Bag x 120, Pretoria, 0001

- 6) Compiling a practical manual on restoration ecology that can be used by land users, extension workers, researchers and academic institutions.

Aims 2 and 3 of Dr. Kellner's project gave rise to the study discussed in this dissertation. Another M.Sc. student, Mr. L. Reynecke, identified two commercial and two communal areas with the assistance of the Department of Agriculture, Potchefstroom². The current project stemmed from and built on Mr. Reynecke's activities. The scope of this project does not allow for the social aspects behind this knowledge transferal, but future studies would benefit from such an added social aspect.



Figure 1.1: The transferal of restoration technology and applicable methods formed a prominent aspect in the implementation of the project.

1.5 Aims of this study

The aims of this study are:

- 1) The evaluation of the short-term sustainability and dynamics of five grass species used in oversowing and restoration application in four degraded semi-arid rangelands.

² ☒ Department of Agriculture, Conservation and Environment: Pasture Section, P/b X804, Potchefstroom, 2520.

- 2) The evaluation of the increase in the richness of rangeland after the restoration procedures were applied, using total grass composition information and comparing the information from different years to one another.
- 3) The evaluation of the improvement in the condition of the vegetation in selected rangelands by processing frequency data using the Integrated System for Plant Dynamics (ISPD) (Bosch *et al.*, 1992).

1.6 Format of the dissertation

The principle part of this dissertation consists of a selection of manuscripts submitted for publication according to the requirements of a variety of scientific journals covering the fields of rangeland ecology and restoration ecology. However, for the sake of orderliness, margins are adjusted throughout, tables and figures and their numbering form part of the text. Photographs and the references thereto, as well as other cross-references, were added.

Where applicable, Chapters 5 - 8 include the following subsections: Abstract, Introduction, Study area, Material and Methods, Results, Discussion and Conclusions and References. Three chapters cover the introductory part of the dissertation (see index), which is followed by a general description of the study areas and the materials and techniques used. The results are discussed in the manuscripts and summarised for the dissertation as a whole concluding chapter. The dissertation ends in a combined reference list.

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Chapter 2. Restoration perspective

2.1 Introduction

Restoration ecology is the discipline which includes those activities which seek to upgrade damaged and degraded land, or the activities to re-create land that has been destroyed, bringing it back to beneficial use in a form in which the biological potential is restored (also see Section 1.2, Chapter 1). The goal of restoring ecological processes is to establish and emulate the structure, function, diversity and dynamics of a specified ecosystem (Harris *et al.*, 1996; Rogers, 1996). Restoration is thus the process of intentionally altering a site to establish a defined indigenous, historic ecosystem (The Society for Ecological Restoration¹, 1991). Restoration, therefore, implies the guided return of ecosystems similar to those that occupied a site prior to human disturbance. The term restoration may be used only where land is to be returned to its former use (Rogers, 1996). Restoration needs the elements of species diversity and genetic diversity within those species as its raw materials to create or recreate complex biotic environments (Rogers, 1996).

Genetic diversity is generally associated with basic research, and not so much with the applied form of ecology. In this sense an interesting perspective of restoration ecology must be explained. Restoration ecology is more than the mere solution of degradation problems (i.e. a form of applied ecology). Although Harris *et al.* (1996) and other pasture scientists largely focus on this practical application of ecology in degraded areas, there exists a more academic side to restoration ecology. According to Jordan *et al.* (1990) ecological restoration has enormous potential for basic research concerning ecosystem function. They argue that in the effort to restore desired end plant community composition and in failing to do so, the environmental and interspecific factors steering the direction of succession and the success of a restoration effort, can be unravelled. For example, when perennial seed is oversown and germinates poorly, questions arise as to what causes the poor germination. The basic principles guiding succession are discovered through the practical side of restoration ecology, increasing our understanding of the ecosystem functions of the created earth. The origin of restoration ecology at the hand of Aldo Leopold (Jordan *et al.*, 1990) was of an academic nature. He established or restored two prairie lands

in an attempt to provide students with hands-on examples of the dynamics occurring in prairie, leading to the discovery of the role of fire in prairie survival.

In the same way, effective restoration strategies for different disturbed areas can be discovered. For example, destruction caused by volcanoes, tornadoes, meteorites, floods, etc. cannot be addressed in the same way as destruction caused by mining activities. Although mining activities and agricultural land is the focus of restoration ecologists, natural occurrences of devastation also exist, e.g. droughts, earthquakes, glaciers, fire and avalanches. Restoration must even be applied to the after affects of wars, urban environments and wetlands. Other areas affected by degradation are discussed in Section 1.1 (Chapter 1). Agricultural practices (and thus degradation) occur on 5% of the soil of South Africa. This includes grazing land (pastures). Grasslands appear uniform on the surface, but species composition in the grasslands varies greatly and the grass populations themselves have high turnover rates (Westoby *et al.*, 1989). Marked year-to-year fluctuations occur in the species composition, closely linked to rainfall patterns (O'Conner & Everson, 1998). The ratio between palatable and unpalatable species change (Behnke & Abel, 1996). Changes in species composition occur also when the grassland is overgrazed combined with droughts (Milton & Dean, 1995; Norton & Sandor, 1997). The vegetation cover and density is reduced, the topsoil is lost through erosion leading to denuded patches (Kellner & Bosch, 1992) and in some areas bush encroachment (Smit *et al.*, 1996).

Restoring the grasslands degraded by overgrazing combined with drought involves processes described by different terms. Some terms were already defined in Section 1.2 (Chapter 1), but some are mentioned here for the sake of refreshment. Restoration is more ambitious than either reclamation or rehabilitation. Other less ambitious interventions are re-vegetation, renewal or redemption. Rogers (1996) defines reclamation as a new use of land and rehabilitation is confined to improvements of a visual nature. Rehabilitation signifies the return of an area to a state where human inputs are no longer required and biotic components are more or less in a dynamic equilibrium. Re-vegetation, on the other hand, describes situations where original vegetation has been destroyed and its reappearance in some form is to be encouraged. Re-vegetation implies re-establishment without involving any ecosystem reconstruction; it is merely the establishment of a stabilising plant cover,

¹ ☒ The Society of Ecological Restoration, 1955 W. Grant Road # 150, Tucson, AZ 85745, USA, ☎ (520) 622 5485 (o), (520) 622 5491 (f), info@ser.org

which can reduce accelerated erosion (Rogers, 1996). Jordan *et al.*, (1990) also support this definition of re-vegetation. Leopold (as quoted by Jordan *et al.*, 1990) defines re-vegetation from another perspective, viz. the most precise and meticulous possible imitation of nature, a novel combination of agriculture and ecology, which correlates more with the definition of restoration. Bradshaw (1997) defines enhancement as the establishment of an alternative ecosystem, i.e. to raise in degree, heighten, intensify or to increase in value, importance or attractiveness. Enhancement means improving the quality of an already good condition to a better condition, but not the recovery of a deleterious condition to an improved condition. Mitigation is not directly linked with restoration, rather it is the process of appeasing, or to moderate the heinousness of something. Mitigation can be an outcome of restoration (Bradshaw, 1997). The terms renewal or redemption may be used in a form that enables flexibility in planning the re-use of the ecosystem (Rogers, 1996). The current project is greatly associated with the processes and patterns of restoration ecology, as well as re-vegetation by oversowing. Please note that the above mentioned definitions of Rogers (1996) in some instances contrast those of Harris *et al.*, (1996) given in Chapter 1, Section 1.2. Definitions by Harris *et al.* (1996) and Bradshaw (1997) are more precise, particularly the definitions for reclamation and restoration. To the definition of rehabilitation, the concept of releasing an area from negative influences should be added. Rogers' (1996) definition of re-vegetation is more acceptable, but the concept of plant introduction must be added. Renewal is the identification of a "new use" of a degraded area. Redemption and rehabilitation are closely related, redemption being the better use of a degraded area. This study included the processes of re-vegetation and restoration, as applied to grasslands.

2.2 Restoration technologies

(Procedures followed in this study are discussed in Chapter 4).

The type of restoration program undertaken depends upon the end-uses for a site (Harker, 1993). Various techniques have been employed in the veld restoration process in order to improve the microclimate for sown seed and to increase the seeds' germination rate and establishment. Two basic techniques are involved with regard to this study, namely soil disturbance (Tainton, 1981) and seed enhancement (coating or pelleting, see Section 2.3) (Siebert²). Soil disturbance improves soil

² ✉ Siebert Seed Consultants, Nieuwestraat 58, Potchefstroom, 2520, ☎ 083 300 6938

structure and water penetration so that germination conditions are enhanced on a temporary basis, allowing species to establish. This improvement in soil structure is only temporary because when not ploughed correctly, soil tends to swell again during rain.

Van der Merwe (1997) distinguishes a number of restoration technologies for reclaiming degraded pastures which include organic, biological and mechanical approaches. The organic approach includes the use of organic material from plants, such as brush packing, sheaf/straw packing and the placement of organic blocks on soil, none of which is covered in the current study. The biological approach includes different sowing methods (Tainton, 1981). The pastures discussed in this dissertation were either overgrazed, leading to a sward of annual composition with bare and denuded patches, or characterised by unpalatable grass species, culminating in poor range condition status (Brown, 1994).

Re-seeding of palatable grass species into sub-plots placed within the pastures could be applied for restoration purposes. Sub-plots are the smaller constituents of a study area (see Chapters 5 – 8 for detailed descriptions of the study areas). Oversewing methods that could be used in restoration practices include broadcast oversewing and row applications (Cairns, 1995; Lochner, 1997; Fig. 2.1). With broadcast application the seed is distributed by hand or with a specific implement over the total soil surface of the study area. For row application the seed is sown in strips by hand or in rows with a specific implement into the furrows after cultivation (Fig. 2.2).

Broadcast mix applications have the highest cost per hectare (R/ha); while row applications of the same mixture would be less expensive (Van der Merwe, 1997). With row application, the entire population of undesirable species are not always removed and the treated area can be exposed to re-invasion by undesirable plants (Roundy & Call, 1988) and subsequent competition (Fair, 1986), unless the oversown species are of higher competitive nature. It is imperative to follow sound management practices in order to encourage the dominance of the oversown grass species (O'Connor, 1995).

With the mechanical approach, a variety of implements can be used to cultivate the soil.



Figure 2.1: The rip plough cultivation method applied to the Kromsprit study area.

Each type of implement has a specific cultivation function and because implement cost (maintenance) are capital-intensive, specific implements are recommended for a specific aim and soil condition (Van der Merwe, 1997).

Farmers most commonly use the rip plough cultivation (tine or sub-soiler implement) method for reinforcement or restoration treatment (Fig. 2.1, Billett, 1988; Van der Merwe, 1997). Several rippers, such as one, two, three, five and seven tine rippers are available. Certain methods, developed by the farmers themselves, such as fitting a plastic pipe to the ripper, are used for sowing seed into the soil (Fig. 2.4). Cultivation methods, such as ripping, are a means of soil disturbance (Tainton, 1981; Cairns, 1995).

Subsoil cultivation with a tine implement can disturb soil (Davies *et al.*, 1986) to given depths, depending on the soil type and structure. The rip plough can loosen the soil deep under the surface, improving water infiltration and is suitable where crust forming occurs (e.g. Sterkfontein soil types, Van der Merwe, 1997, Fig. 2.1 & 2.3).



Figure 2.2: Seeds are oversown in the rip furrows after the rip plough cultivation method was applied.



Figure 2.3: An example of the rip ploughs used in the rip plough cultivation method as applied during restoration technologies.



Figure 2.4: A more economical way is to combine the rip and oversowing treatment.

2.3 Seed types for restoration

Restoration experts obtain seed for projects either by purchasing it from a commercial vendor or by collecting it themselves. For the purists, using seed of a genotype alien to the region, but available in the commercial sector, would be incompatible with true ecosystem restoration. True, but if the grass species that occurred previously in the area are not available in seed form, not from farmers, nor from the soil seed bank, it is permissible to rather use previously occurring grass species albeit their genotypic variation from the original community. It would be far better to address erosion with species that did occur in the area than to wait with restoration just because the genetic equivalent of a previously occurring species is not available. The option of buying seed from a respected supplier of locally derived seed has several advantages. These suppliers are often able to produce large quantities of seed, below the cost of seed collected by the restoration experts themselves. Purchased seed often has less chaff and trash which results in reduced overall bulk. The supplier may also provide information about the purity and viability of the seed as well as about the number of seed per kilogram. They should also provide guarantees about germination rates (usually between 20-30% for grass

species as stipulated by the Plant Improvement Act, see SA 1995:174 in the reference list). The pure live seed and the number of seed per kilogram are important when deciding on the amount of seed needed for a specific project (Lochner, 1997).

Depending on the seed type and morphology, approximately 3 kg/ha more seed (species with unchaffy seeds) is required for broadcast application than in the case of row application (Van der Merwe, 1997). Broadcast application of chaffy grass seeds are approximately double that of row applications, e.g. recommended row application for *Antheophora pubescens* (wool grass) is 6 kg/ha whereas broadcast application of the same species is 12 kg/ha (Advance Seed², 1997). Chaffy seed is grass seeds with glumes and appendages greater than 4 mm (ISTA³, 1999). Distinction is made between enhanced and untreated seed. Three different types of enhancements can be distinguished, namely: pre-sowing hydration treatments (priming), coating (encapsulating) technologies and seed conditioning. Pre-sowing hydration treatments include non-controlled water uptake systems (methods in which water is freely available and not restricted by the environment) and controlled systems (methods that regulate moisture content preventing the completion of germination). Three techniques are used for controlled water uptake, namely priming with solutions or solid particulate systems or by controlled hydration with water (Taylor *et al.*, 1998).

Coating technologies include pelleting and film coating. Coatings may serve as delivery systems. Seed conditioning equipment upgrades seed quality by physical criteria, such as the removal of poor quality seeds that are immature, damaged or off-sized and of contaminants such as other crop seeds, weed seeds and/or inert matter (loose glumes, sticks, etc.) (Taylor *et al.*, 1998). Integration of these different methods can be performed. The seed coating technology is applicable to the current study. Seeds vary greatly in size, shape and colour. In many cases, seeds are small or irregular in size, making singularisation and precision placement difficult. In addition, seeds should be protected from a range of pests that attack germinating seed or seedlings. Seed-coating technologies facilitate mechanical sowing to achieve uniformity of plant spacing, and can act as a carrier for plant

² ☒ Advance Seed, P.O. Box 414, Krugersdorp, 1710, South Africa, ☎ + 27 11 762 5261 (o), +27 11 762 4111 (f).

³ ☒ International Seed Testing Association, Secretariat, P.O.Box 412,8046 Zurich CH-Switzerland, ☎ +41 1 377 60 00, Fax +41 1 377 60 01, e-mail istach@iprolink.ch

protectants. Materials can also be applied to the target zone with minimal disruption to the soil ecology and environment. Pelleting is defined as the deposition of a layer of inert materials that may obscure the original shape and size of the seed, resulting in a substantial weight increase and improved plantability; while film coating retains the shape and general size of the raw seed with a minimal weight gain. The coating should result in a more or less continuous coating, which eliminates or minimises product dust-off. Both coating methods may contain polymers, pesticides, biologicals, identifying colorants or dyes and other additives, such as soil or fertiliser (Taylor *et al.*, 1998). The type of material and procedure used in enhancement can have a number of objectives, namely to improve the moisture regime surrounding the seed. The capsule around the seed can provide a source of plant nutrients in close contact with the rootlet of the germinating seed, to protect the seed against rodents, birds and insects. The basic material for seed enhancement by coating or encapsulation is usually either lime superphosphate or rock phosphate. An essential ingredient is an adhesive such as carboxy-methylcellulose (CMC) or gum arabic (Tainton, 1981). The artificial coat is water and oxygen permeable and can contain trace elements and/or fungicides. Enhancement overcomes poor ballistic qualities and small size, giving the treated seed enough weight to be grounded (Siebert²).

2.4. Seed purity

The word seed is used throughout the dissertation, instead of the word caryopsis. The term pure seed is the percentage of seeds that actually correspond with the identification label on the seedbag (ISTA³, see Section 2.3). As it is generally not possible to remove all impurities completely during the cleaning process, standards have been set to determine the composition of the seed. The object of a purity analysis is to determine, first of all, the percentage (by weight) of the constituent components in the sample being tested, and by inference the composition of the seed lot. Secondly, the identity of the various species of seeds and inert particles constituting the sample (Seed Control Directorate of Genetic Resources, 1999) are determined. There are a number of definitions for seed purity, of which only analytical and species purity applies to the present study. Analytical purity is the percentage of the material in the bag, that is the intact seed of the species named on the label. It is estimated by a small sample (approximately a tenth of the weight according to the Seed Control Directorate of Genetic Resources, 1999) from the bag. In grass seeds, the most common impurities are empty florets. Species purity is

determined from a larger sample (8 x 100 seeds according to the Seed Control Directorate of Genetic Resources, 1999) and expressed as the weight of seeds or particles of other not specified species relative to the weight of all the seeds examined (Thomson, 1979). Seed purity is an indicator of the percentage of seeds present for germination, whether viable or not.

In so-called impure seed lots, seeds of other species as well as stalks, sand granules and empty florets are present. Sowing impure seed would result in a pasture consisting of other plant species and of preferred plant species at a lower than anticipated density. One manner in which to lower the initial costs of restoration is to determine the least amount of seeds necessary for a treatment. The seeds used in this project had pureness indices varying between 98% and 52% depending on the seed type used (see Section 4.2.1, Chapter 4).

2.5 Seed viability, germination and seedling survival

A viable seed is a living seed (Bewley & Black, 1983) capable of developing and surviving independently (Cowie, 1989) and is influenced by temperature, moisture content of the soil and oxygen pressure (Roberts, 1972).

When a viable seed is wetted, water is taken up, respiration, protein synthesis and other metabolic activities begin and after a certain period of time the embryo emerges from the seed, generally radicle first, in other words the seed has germinated (Bewley & Black, 1983; Thomson, 1979). The distinction between germination rate and germination ability (germinability) or capacity is that germination ability is the maximum percentage of viable seeds that germinate under favourable conditions. Germination rate is the germination percentage obtained after a certain time under certain stipulated conditions that may or may not be optimal (Bewley & Black, 1983). The inherent potential of the seeds to germinate is only a fraction of the equation to determine the species composition of the communities under observation. A large number of factors (inherent and environmental) contribute to the germination success of seeds (Young, 1988).

Pertaining to this study, seedling survival rate was studied in the laboratory and compared with responses to the parental (field) environment. The objective was to

interpret the ecological implications thereof, particularly as re-establishment of perennial grass is poor in degraded and disturbed areas of South Africa's semi-arid regions (Baxter *et al.*, 1993). Comparisons were drawn between seedling establishment in seed trays in greenhouse trials, seed germination rates in the laboratory and seedling survival in the field tests to evaluate the success rate, purity of the seed and germination of the grass species under discussion. According to Barbour *et al.* (1987) environmental conditions determine the number of seedlings that will survive past the germination phase.

As discussed in Chapter 1, Section 1.3.1, one of the parameters of population dynamics is the different growth stages of a species. It is appropriate to single out the survival of seedlings at this point. Seedlings and/or tillers are the visible progeny of a generation of grass and, therefore, an estimate of the following generation. The number of seedlings and/or tillers is an indicator of a species ability to recover after disturbance (Fair *et al.*, 1999) and form part of the measurements used in adopting sound management practices (Meyer & Schmid, 1999).

The ultimate objective of testing for germination is to determine the maximum germination capacity of the seed and to provide results that can be used to compare the value of different seed lots. Testing under field conditions is normally unsatisfactory, as the results cannot be repeated with reliability because of varying environmental conditions. Laboratory methods in which the external (environmental) conditions are controlled to give the most regular, rapid and complete germination for the majority of samples of a particular species have, therefore, been developed. The external conditions have been standardised to reproduce test results within limits as near as possible to those determined by random sample variation. Germination of a seed in a laboratory test is the emergence and development of the seedling to a stage where its essential structures indicate whether or not it is able to develop further into a satisfactory plant under favourable conditions in the field. All seeds require moisture, temperature (in the range of 10 °C and 30 °C), and adequate oxygen supply. Some seeds have specific light requirements for germination, e.g. *Poa* spp. The role of light in seed germination is, however, very complicated. Most grass seeds will germinate whether light is present or not, but the presence of light prevents excessive etiolation of the seedling and promotes the formation of chlorophyll (Seed Control Directorate of Genetic Resources, 1999). Suppressed etiolation and the formation of chlorophyll make the examination of

seedlings for possible defects easier for the seed analyst. The best temperature for maximum germination is likely to be different for different kinds of seed. The Germination Committee of the International Seed Testing Association (ISTA) worked out the best possible germination conditions for many kinds of seed. The phrase "in the course of a germination test" in the definition of percentage germination, implies that there is a time limit to the test. The condition for germination is also specified because some kinds of seed may be dormant and will not germinate under the usual conditions without undergoing dormancy breaking processes. The moisture and air supply to the seed are controlled by the substrate, i.e. sand or paper, in/on which the seed is placed for germination purposes. The apparatus for controlling temperature depends on the kind of substrate and whether or not light is required (Seed Control Directorate of Genetic Resources, 1999).

2.6 Soil seed bank

2.6.1 The ecology and definition of a soil seed bank

The viable seeds and fruits present in or on the soil are referred to as the seed pool or seed bank (Barbour *et al.*, 1987; Leck *et al.*, 1989). Some of these seeds germinate to become seedlings. The environment acts as a sieve, as some seedlings become established and other seeds remain in the seed pool. Near the end of the growing season, new seeds are produced, and another seed pool is available for the next generation. The length of time that seeds survive in the seed pool is related to growth form and environment (Barbour *et al.*, 1987). The behaviour and fate of the seed fraction of a population are often of importance to its overall dynamics (Silvertown & Lovett-Doust, 1993). From the soil seed bank the next generation of a species is born (Barbour *et al.*, 1987) and the species is propagated. In a rangeland context, fodder for the following season can be produced.

Large numbers of seeds may accumulate in the soil seed bank. Seed densities are highest in frequently disturbed habitats and the species most strongly represented in the soil are often those with the shortest life span aboveground. The spatial distribution of seeds is usually clumped because dispersal distances from the parent plant tend to be limited and animal dispersal agents may concentrate them in their faecal deposits. The seed bank can serve as an important reservoir of genetic variation and it may increase the population numbers if the recruits from the seed

bank to the active population do not belong to few numerically dominant genotypes. That is, if the desired species are present in the soil seedbank. Seeds often have particular germination requirements that restrict the appearance of new plants to safe sites that may be limited in number (Silvertown & Lovett-Doust, 1993).

2.6.2 The importance of investigations of the soil seed bank in the study areas

The soil seed bank has been identified as an important determinant of the floristic and structural changes in field succession. Some evidence suggests, however, that the soil seed bank may be of minimal importance in determining the course of succession in grasslands (D'Angela *et al.*, 1988). The loss of the vegetative stage in a plant's life history, even if absent for several decades, does not necessarily show that the species is not present as dormant seed. This phenomenon can be applied in nature conservation to recreate former or endangered plant communities or to maintain species-rich plant communities, even though the potential for re-colonising large areas from the soil seed bank seems quite weak (Du Toit & Alard, 1995). In degraded areas, the re-appearance of plant species may depend on their persistence in the soil seed bank as a 'memory' of the original plant community (Bakker *et al.*, 1996). Also, in semi-arid areas, the main reproductive strategy of perennial grass species is through seed dispersal as opposed to vegetative reproduction as in montane areas (Baskin & Baskin, 1998). For the current study, the soil seed bank reveals the following important aspects of the natural vegetation:

- 1) The soil seed bank reveals the structure of the seed banks of both the natural vegetation and the vegetation present at the various stages of restoration. Seed bank structure is expressed as the density of each species, the number and type of species, and the dominant species in the soil seed bank.
- 2) The soil seed bank reveals the species richness in the seed bank and their relationship with the standing vegetation.
- 3) It can be a source or a safe site for certain "rare" plant species.
- 4) As the forerunner to seedlings, the seed in the soil may ensure self-sustainability of the plant community.

The aim of studying the soil seed bank in the current study is to monitor if a self-sustainable community has established on the restored sites. The latter will be true when the species are able to reproduce and regenerate new plants successfully without further intervention by man. One measure of successful establishment is to assess the amount of each growth stage present in the field. That is, seed, seedling and/or tiller, vegetative and reproductive stages. A population represented in all these stages is termed as a healthy population and able to maintaining itself in the habitat.

For a plant species to establish, it has either to germinate from a seed or reproduce vegetatively. When the species found in the seed bank correspond with the standing vegetation, the following scenarios can be applicable (Barbour *et al.*, 1987):

- 1) The species might have developed from a **transient seed bank**, being a seed pool represented by species that will either die or germinate within a year. Seeds of long-living perennials in moderate environments usually survive for only short periods in the seed pool. Transient seed pools have little impact on the population, aside from their numbers and position in safe sites. They usually originate from annuals growing in predictable habitats where successful reproduction is essentially a sure thing.
- 2) The species might have developed from a **persistent seed bank**, being a seed pool that accumulates seeds over a longer period of time. Annual species in very harsh conditions tend to have extremely long periods as viable seeds. Persistent seed pools are characteristic of ephemeral plants, perennial herbs and/or shrubs occurring in unpredictable environments. Permanent seed pools contain a multitude of genotypes, produced in past environments and potentially capable of germinating at any time. This accumulation of genotypes from the past increases the chance that a well-adapted genotype will be present following a germination event. This is particularly important for annuals in unpredictable environments. Short-lived semelparous perennials occupy habitats for two to three years. They depend on seed being present in the soil to begin growth immediately when habitat becomes available. Typically, seeds of the "biennials" live long enough to survive extended

periods when habitat is unavailable and they have few special requirements for breaking dormancy (Barbour *et al.*, 1987).

There are several more reasons why a soil seed bank that is uncharacteristic of the standing vegetation exists. Seeds are formed at the end of the growing season - referring also to the drier part of the year (Barbour *et al.*, 1987). When the vegetation is grazed in this time of year, the species cannot reproduce and they cannot add seed to the seed bank (Bertiller, 1996). The particular species then develops a seed debt for the next year. This circle can repeat itself to the extent that the particular species become extinct. The same applies for untimely fire management (Trollope, 1992).

2.6.3 Methods for establishing a persistent soil seed bank

The study areas had natural seed banks prior to the treatment. By the subsoiling cultivation and oversowing treatment, seeds were added to the topsoil. Other sources for seeds for the soil seed bank are the impurities coming with the seed mixture sown into the study areas, as well as seeds carried in by either the wind, water or animals. No seed lot ever contains only what is stated on the identification label of the packet of seed (Seed Control Directorate of Genetic Resources, 1999). Also, the minimal number of other seeds in the seed lot, as well as seeds still present in the topsoil, adds to the overall composition of the soil seed bank.

Seed of a specific species in the soil can germinate and form a population. When the germinated population forms seed, the population replenishes the soil seed bank and the population can sustain itself. Self-sustainability should compensate or allow for environmental variability, as a number of years of drought in combination with sustained heavy grazing can reduce and eliminate an established population of grass species. Rapid attrition of the seed bank follows, as the seed production *in situ* is limited, the seeds present live only two to three years and dispersal is poor (O'Connor & Pickett, 1992; Bertiller, 1996).

When the degradation process progresses to the point where no seed of preferred species are available in the soil seed bank, seeds must be added to the topsoil (Roundy & Call, 1988). Climate and management (Akinola *et al.*, 1998a; Pakeman *et al.*, 1999) will then determine the composition and quality of the pasture.

As mentioned in Chapter 1, Section 1.3.1, the turnover rate between the different life growth stages of a plant species needs consideration in determining the sustainability of a grass population. Distinction must be made between the seed, seedling, vegetative and reproductive stages of each grass species under consideration. Seed densities were determined by the soil seed bank analysis (detailed explanation follows in Chapter 4, Section 4.2.2) and for most of the study areas integrated with the density data of the seedling, vegetative and reproductive plant growth stages of each of the grass species.

2.7 Economic aspects of restoration through oversowing

The common perception of land managers is that restoration of rangeland is not cost effective, especially over the short term. The capital investments and labour intensity do not seem worthwhile to the land manager, especially in arid and semi-arid areas where very erratic and unpredictable rainfall patterns persist. High cost of seed also creates a negative attitude towards restoration technology (Milton & Dean, 1995). Costs further constitute professional advice, fuel (if cultivation procedures are used), labour force remuneration and loss of income due to the removal of animals from the area for the establishment period of the grass species sown in. Using grass seed mixtures and only the seeds of those grass species adapted to the given area, can reduce the costs of restoration (see the example below). The economical and ecological loss of land left to degrade compared with the economical and ecological benefits of land where restoration was applied tilt the scale in favour of restoration ecology over the longer term. This is especially applicable for areas that have been degraded to such an extent that they have passed a certain threshold of degradation (Bosch & Gauch, 1991; O'Connor, 1993). The threshold could be passed due to poor vegetation cover or quality and abundance and a decrease in the condition of soil physical and chemical characteristics (Kellner & Bosch, 1992). The production of such an ecosystem is too low to carry livestock on a sustainable basis. Improving the link between ecology and rangeland management requires linking ecological processes and the costs of manipulating them to financial returns and risk (Brown, 1994).

The following example is given to demonstrate that restoration technology can be viable and cost effective over a certain period of time when applied to a livestock production system. Prior to restoration, degraded areas have no or limited carrying

capacity. While restoring such degraded patches, only the patches that are restored need to be fenced and the rest of the pasture is still available for use. A comparison is made between costs and profit of unrestored and restored pasture as applied in the restoration of a degraded area in the Koster District (adapted according to work done by Van der Merwe, 1997).

Unrestored pasture:

For the sake of the example a total of 880ha pasture is used. An 880 ha pasture with a grazing capacity of 8 ha/LSU can carry 100 cows (1 small frame cow is approximately 450 kg = 1.1 LSU, Jordaan⁵, 1999, February. personal communication).

The following information is given: weaning percentage is 70%

weaning mass is 200 kg

current meat prices are R 4.80 (Jordaan, 1999, February 15 personal communication).

Selling animals raised on an unrestored pasture:

100 cows x 70% x 200 kg x R 4.80 = R 67 200

- 10 220 (lick cost per year)

= R 56 980 per year.....2.1

Restored pasture:

It is less expensive to use a mixture of different seed types than a mono species applications in reinforcement or restoration programs, because grass seed mixtures require less seed of each species in proportion than a single seed application (Van der Merwe, 1997, Tab. 2.1 versus Tab. 2.2.). Three grass species suited for the study area, are e.g. *Panicum maximum*, *Chloris gayana* and *Digitaria eriantha* (De Wet, 1997). The cost for single species application for these three grass species is indicated in Table 2.1.

⁵ ✉ Jordaan, D., Dept. of Agriculture: Conservation and Environment, Louis le Grange Building, c/o Wolmarans and Van Riebeeckstr., Private Bag x 484, Potchefstroom, 2520, ☎ (018) 297 5330.

Table 2.1: The total cost for mono species application of grass seeds used during restoration practices

Grass species used during oversowing	Recommended sowing density per ha (kg/ha)	Cost per kg (R/kg) (February, 1999)	Total (R/ha) (February, 1999)
<i>Panicum maximum</i>	5	36.48	182.40
<i>Chloris gayana</i>	5	25.08	125.40
<i>Digitaria eriantha</i>	5	22.80	114.00

Part of the cost per hectare is estimated by dividing the amount of seed per ha by the total amount of seed in the seed mixture. This value is then multiplied with the price of each seed type and amounts to the initial oversowing cost per hectare (see calculation 2.2 and Tab. 2.2)

$$*5 \text{ kg/ha P. max} \times \text{R } 36.48/\text{kg} = \text{R } 12.15/\text{ha}$$

$$15 \text{ kg/ha} \dots \dots \dots 2.2$$

Table 2.2: The initial oversowing costs per hectare using grass seed mixtures for restoration purposes

Species	Recommended sowing density per ha (kg/ha) ¹	Adapted density per ha (kg/ha) ²	Cost per kg (R/kg) ¹	Adapted cost of seed per ha (R/ha) ²
<i>Panicum maximum</i>	5	*0.333	36.48	12.15
<i>Chloris gayana</i>	5	*0.333	25.08	8.35
<i>Digitaria eriantha</i>	5	*0.333	22.80	7.60
Total	15	1kg x 5	84.36	28.10 x 5 = 140.50

¹ Advance Seed⁴, 1997

² Example of the computing of the adapted density per ha (Van der Merwe, 1997):

Cultivation with a 78 kW tractor and a 3-tine ripper on a clay soil amounts to an amount of R 60.00/ha (Van der Merwe, 1997), giving a total amount of R 200.50/ha

(R 60.00 + R 140.50, Tab. 2.2) for the restoration of the pasture. Treating 880 ha would amount to R 200.50 x 880 = R 176 440.00. But it is suggested that a smaller area should be restored (e.g. 550 ha) at a any time, allowing for grazing pastures for the animals as well as for financial security. It is recommended that no grazing be allowed in the restored areas during the first two to three years after the restoration treatment depending on the prevailing climate regime. Years 2 and 3 entail no costs or profit during the establishment in the area of pasture that is restored. After year 3, with a 93-100% germination rate, the carrying capacity can be enhanced to 5ha/LSU and theoretically only 550 ha, instead of 880 ha, would be needed for the same 100 cows. Keep in mind that a further 330 ha is still available for later addition of cattle. With the increased carrying capacity weaning percentage on the restored 550 ha area increases to 85% (Du Plessis⁶, 1999, personal communication) and weaning mass to 230kg. Costs in year 4 would then be as follows:

100 cows x 85% x 230 kg x R 4.80 = R 93 840 (worth when sold for meat)
 - 110 275 (restoration costs for 550 ha)
 - 10 220 (lick cost)
 = - R 26 655 in year 4.....2.3

In year 5 and the profit could be

R 93 840
 - 11 242 (lick cost with 10% increase)
 - 26 655
 = R 55 943 per year.....2.4

In year 6 and the following years the profit could be

R 93 840
 - 12 264 (lick cost with 20% increase)
 = R 81 576 per year.....2.5

The longer the period to show profit as in the sixth year of this example, the more reluctant farmers will be to take up the option, regardless of the economic benefits

⁶ ☒ Du Plessis, F., Dept. of Agriculture: Conservation and Environment, Section Agricultural Economy, Private Bag x 804, Potchefstroom, 2520, ☎ (018) 299 6568.

(Crosthwaite *et al.*, 1996). Theoretically, 100 cows can graze the unrestored 880ha of pasture with a 8ha/LSU carrying capacity. After restoration, 100 cows can graze the smaller area of the initial 550 ha. That still leaves a potential of 330 ha that can carry 66 more cows after restoration. The unrestored pasture has a given profit from the start with no initial costs other than price of the cows, the lick, medicine and transport. The restored pasture, on the other hand, is profitable only in the sixth year after restoration. The profit from the restored pasture exceeds that of the unrestored pasture with approximately R 14 000. Restoration is not profitable over the short-term, but definitely over the long-term. Therefore, factors that increase restoration costs must be weighed and examined carefully to find the most viable option for the restoration practice. The use of grass species not adapted to the specific study areas, cause restoration costs to increase. Other factors that will increase the costs are the use of plough methods unsuited to the specific soil, as well as grazing in the second or third year after the restoration application. It is imperative to use the correct management and restoration technique as this will ensure desirable results and will be cost effective over the long-term. Management would involve grazing strategies (e.g. rotational grazing) or burning to remove excessive organic material. Detailed strategies for rotational grazing, burning strategies, as well as cost calculations can be obtained from the Department of Agriculture.

The other scenario obviously involves drought and other setbacks. Some restoration strategies, though, are not dependent of irrigation and can be applied in dryland systems. In this study, the restoration strategies proofed successful.

This chapter discussed some concepts used in restoration ecology, some technologies and seed types appropriate for restoration, as well as the importance of seed purity and viability. Germination and actual seedling survival differs greatly. Another factor that has an important role is the availability of seed in the soil seed banks. The chapter was concluded with the profitability of the applied restoration practice.

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Chapter 3. General description of the study areas

3.1 Introduction

Distribution of and variation in the Grassland Biome are the result of the subtle interplay of climate, topography, soil type, veld fires and grazing. Fires and grazing fall beyond the scope of the current study. The study areas were not burned or grazed. The geology and climate depend upon the geographic location of an area (Van Wyk, 1994), and determine the type of soil formed (Bowles, 1984). The underlying geology and soil determine the type of vegetation found in the given area (Pakeman *et al.*, 1999). For these reasons, general geographical and geological data as well as the existing vegetation pertaining to the study areas Tweefontein, Totiuskraal, Kromspruit and Davidskatnagel are given below. The Department of Agriculture: Geology Section¹ conducted the soil analyses.

In the current study, the study areas (all situated in the North West Province of South Africa), are named after the farms or districts on/in which they are situated (Figure 3.1). In Chapters 5 - 8 each study area is discussed in detail.

3.2 Tweefontein

3.2.1 Geographic location

The Tweefontein study area (25°47'S, 26°45'E) is situated on the commercial managed farm of Mr. D. Pelsler, 1300 m above sea level (Land Type Survey Staff, 1984a), 15 km north west of Koster (Figure 3.1).

3.2.2 Geology

The study area is underlain by rocks of the Pretoria Group, Transvaal Sequence (Keyser, 1997). The quartzites belong to the Timeball Hill and Daspoort Formations, whereas the shales belong to the Strubenkop, Silverton and Timeball Hill Formations. The general regional dip is seven degrees towards the north and north east (Schulze *et al.*, 1997).

3.2.3 Land and soil type

The Land Type Survey Staff (1984a) chose broad soil patterns for the compilation of the common legend to the land type maps. The farm Tweefontein is situated in

¹ ☒ Department of Conservation and Environment: Geology Section, P/bag X 804, Potchefstroom, 2520.

the Ea29a, Ea29b and Ae59d land types. The land types were conveniently numbered according to the broad soil patterns (catena). When a land type was arranged in a particular soil catena, the next available number in the soil catena was allocated to the land type. For example, the number Ea39 was allocated to the 39th land type in the broad soil catena Ea. Often soil of the same land type occurs as islands separated by other land types. Each of the separate appearances is identified by the system Ea29a, Ea39b. The A-soils are not in direct contact with the water table and might include any of the following soil forms: Inanda, Kranskop, Magwa, Hutton, Griffin or Clovelly. The land does not qualify as a plinthic catena and one or more of the above mentioned soil forms cover at least 40% of the area.

The study area at Tweefontein is classified as the Ae59d land type, i.e. red-yellow apedal, well-drained soils. It is a red soil with a high base saturation, more than 300 mm deep and with no dunes (Land Type Survey Staff, 1984a). The soil consists of the Hutton msinga soil form (Schulze *et al.*, 1997). Facing south, the convex mid-slope is 4° (Land Type Survey Staff, 1984a). The rocks gave rise to a sandy-clay-loam soil (25% clay) with a pH_{H₂O} between 6.16-7.13. Phosphorous and potassium are readily available as nutrients in the plants at this particular study area. Water is easily absorbed and an effective depth of 1200 mm (Land Type Survey Staff, 1984a) includes the orthic topsoil (Soil Classification Working Group, 1991).

3.2.4 Existing vegetation prior to restoration application

The farm is situated within the Grassland Biome (Rutherford & Westfall, 1994) and classified as the Bankenveld (A61) Veld Type by Acocks (1988). The Tweefontein study area was characterised by the following woody species: *Acacia karroo*, *A. mearnsii*, *Rhus lancea*, *Asclepias fruticosa*, *Ziziphus mucronata*, as well as a number of grass species, namely *Cymbopogon plurinodis*, *Heteropogon contortus*, *Elionurus muticus*, *Eragrostis gummiflua*, *Melinis repens* and *Setaria nigrirostris*, according to field surveys in 1995. These grass species were mostly unpalatable (Van Oudtshoorn, 1999). This open treeveld (Schulze *et al.*, 1997) with the dominance of *C. plurinodis* would thus preclude cattle from reaching their full mass potential, unless the quality of the pasture is improved. The restoration application (Section 4.1, Chapter 4) addressed the unpalatable sward composition. The restoration technique was applied to the degraded field (study area). The study area was not a benchmark for the restoration application.

NORTH WEST PROVINCE


-  DISTRICT BOUNDARIES
-  STUDY AREAS



Figure 3.1: The location of the study areas in the North West Province of South Africa (supplied by Dept. of Geography and Environmental Study; Cartographic and GIS Services)

3.3 Totiuskraal

3.3.1 Geographic location

The Totiuskraal study area (26°53'S, 27°13'E) is located 50 km south east of Potchefstroom on the farm of Mr. P. Linde, with an altitude of 1364 m above sea level (Land Type Survey Staff, 1984b; Figure 3.1).

3.3.2 Geology

The geology of the Totiuskraal study area includes diabase of the Transvaal Sequence (Keyser, 1997) together with Hekpoort Formation lava (part of the Pretoria Group). Shale, slate and quartzite of the Pretoria Group also occur in the area. The quartzite usually forms crests and scarps, while footslopes are situated on the diabase, lava, shale and slate (Land Type Survey Staff, 1984b). Weathering typically leaves rounded hillocks.

3.3.3 Land and soil type

The Totiuskraal study area is of the land type Bc25c (Land Type Survey Staff, 1984b). The B-type soil patterns (see Section 3.2.3) include the plinthic catena characterised by upland duplex and marginalitic soils. The soils of the Bc land type are widespread, eutrophic red soils (Land Type Survey Staff, 1984b). The sandy-clay-loam texture of the soil (29% clay) has pH-values_{H₂O} between 4 and 5 causing the minerals in the soil to be available to the plants. The study area has a concave mid-slope of 3° facing west with orthic soil (largely eroded) overlying a red structured B-horizon (Land Type Survey Staff, 1984b).

3.3.4 Existing vegetation prior to restoration application

As part of the Grassland Biome (Rutherford & Westfall, 1994), the veld type is classified as Mixed Grassland by Acocks (1988). The Totiuskraal study area contained the following grass species prior to the restoration application: *Aristida canescens*, *A. congesta*, *Tragus berteronianus* and *C. virgata*. All the grass species, except *Aristida canescens* are annual, pioneer grasses occurring in degraded and disturbed areas (Van Oudtshoorn, 1999). The restoration technique was applied to this degraded area with its annual grass composition in a twofold attempt to improve the palatability of the sward composition and to halt the sheet erosion that started on the upper half of the slope. Without the restoration treatment the erosion could have spread and made the area completely unavailable for grazing.

3.4 Kromspruit

3.4.1 Geographic location

Kromspruit (25°06'S, 26°29'E) is a communal managed tribal trust area of the former Bophuthatswana self-governing state, 20 km north west of Madikwe, 945m above sea level (Land Type Survey Staff, 1984a, Figure 3.1).

3.4.2 Geology

Norite (Keyser, 1997) belonging to the Rustenburg Layered Suite of the Bushveld Igneous Complex (Land Type Survey Staff, 1984a) occurs in Kromspruit. Other rocks include bronzite, harzburgite, shale and quartzite.

3.4.3 Land and soil type

The Kromspruit study area is composed of the Ae32d (see Section 3.2.3) and Ea9d land types. The unit of the Ea landtype indicates land with high base status, dark coloured and/or red soils, usually clayey, associated with basic parent materials. A land type more than half of which is covered by soil forms with vertic, melanic and red structured diagnostic horizons qualifies for inclusion in unit Ea (Land Type Survey Staff, 1984a). The soil has a sandy-clay-loam texture with a clay percentage of 23% and a $\text{pH}_{\text{H}_2\text{O}}$ between 7 and 8 (Department of Conservation and Environment: Geology Section) releasing calcium and magnesium to the vegetation (Barbour *et al.*, 1987). The soil is poorly drained and aerated (Soil Classification Working Group, 1991). The study area is part of a valley floor with a 3° slope facing north (Land Type Survey Staff, 1984a).

3.4.4 Existing vegetation prior to restoration application

Situated in the Savanna Biome (Rutherford & Westfall, 1994) this Bankenveld Veld Type (Acocks, 1988) is characterised by Clay-thorn Bushveld (Bredenkamp *et al.*, 1996). The area near Kromspruit is characterised by grasses such as *C. virgata*, *Cynodon dactylon*, *Urochloa mosambicensis*, *Brachiaria eruciformis* and *A. canescens*. Of these species, only *C. dactylon* and *U. mosambicensis* have high forage values (Van Oudtshoorn, 1999) and they constitute less than 15% of the vegetation composition. This vegetation was partly altered when the restoration technique was applied to the study area. The restoration application addressed bush encroachment as well as low productivity of the annual grass composition, provided approximately 1 ha of highly productive pasture.

3.5 Davidskatnagel

3.5.1 Geographic location

Davidskatnagel (25°22'S, 26°30'E), a communal land tenure system 17 km north of Madikwe, situated 960 m above sea level (Land Type Survey Staff, 1984a; Figure 3.1).

3.5.2 Geology

Norite (Keyser, 1997) belonging to the Rustenburg Layered Suite of the Bushveld Igneous Complex (Land Type Survey Staff, 1984a) occurs in the Davidskatnagel study area. Other rocks include bronzite, harzburgite, shale and quartzite.

3.5.3 Land and soil type

Davidskatnagel is situated in the Ae32d and Ea9d land types and is similar to Kromspruit (see Section 3.4.3). The soil has a sandy-clay-loam texture with a clay percentage of 29% and a $\text{pH}_{\text{H}_2\text{O}}$ of 7 that release phosphorous and potassium to the vegetation. The study area is part of a straight footslope with a level aspect (Land Type Survey Staff, 1984a). The soil has poor drainage and aeration (Soil Classification Working Group, 1991).

3.5.4 Existing vegetation prior to restoration application

This community is part of the Savanna Biome (Rutherford & Westfall, 1994), of the Bankenveld Veld Type (Acocks, 1988) with a typical Clay-thorn Bushveld (Bredenkamp *et al.*, 1996). The composition of the vegetation near Davidskatnagel includes *C. virgata*, *A. congesta*, *Sporobolus ioclados*, *B. eruciformis*, *Urochloa panicoides* and *Panicum coloratum*. The latter species has a high forage value (Van Oudtshoorn, 1999) but occurred in only 3% of the study area. *S. ioclados* and *B. eruciformis* are moderately palatable but the other species are of poor forage quality (Van Oudtshoorn, 1999). The oversown species were added to this existing composition of grass species. The restoration treatment was not aimed at oversowing more of the already present grass species but at introducing more productive, perennial grass species with higher fodder quality.

3.6 Climate

The emergence, survival and establishment of seedlings constitute key factors in the maintenance and recovery of vegetation cover. In arid and semi-arid

ecosystems, the success of seedling survival is strongly coupled to water availability in the soil (Bertiller *et al.*, 1996). For one, water availability in the soil is dependent upon the rainfall of the area (Spaeth *et al.*, 1996), and the influence of rainfall on the establishing plants should be considered. With changing seasons, plants are exposed to short and long-term fluctuations in temperature. Knowledge of the influence of temperature on growth cycles would be useful in understanding the response of plant growth to temperature. This understanding leads to optimised fodder production (Greenfield & Smith, 1992). The following table summarises the average long- and short-term rainfall as well as the average minimum and maximum temperatures of each of the study areas (Tab. 3.1, Figure 3.2).

Table 3.1: The average rainfall and temperature of the four study areas

	Twefontein	Kromspruit	Davidskatnagel	Totiuskraal
Rainfall: average long-term (mm/yr.)	491.1 ¹	604 ¹	604 ¹	617.1 ¹
Rainfall: average short-term (mm/yr., 1995-1999)	595.8 ¹	516.8 ¹	310.9 ¹	773.3 ¹
Temperature: average minimum (°C)	9.4 ²	11.2 ³	11.2 ³	10.9 ²
Temperature: average maximum (°C)	25.3 ²	26.6 ³	26.6 ³	25.4 ²

¹ Department of Conservation and Environment: Geology, Potchefstroom

² Land Type Survey Staff (1984a and 1984b)

³ Bredenkamp *et al.* (1996)

The enormous difference between the average short-term rainfall of Kromspruit and Davidskatnagel, which are not that far apart to merit such a difference in rainfall. On the calculation of these averages. None of the weather stations closer to the two study areas provided sufficient rainfall data for a year, let alone five or twenty years. So instead the closest weather stations with sufficient data was chosen, using one station to the north of the study areas and two to the south. For Kromspruit the average was calculated using information from the Goudini

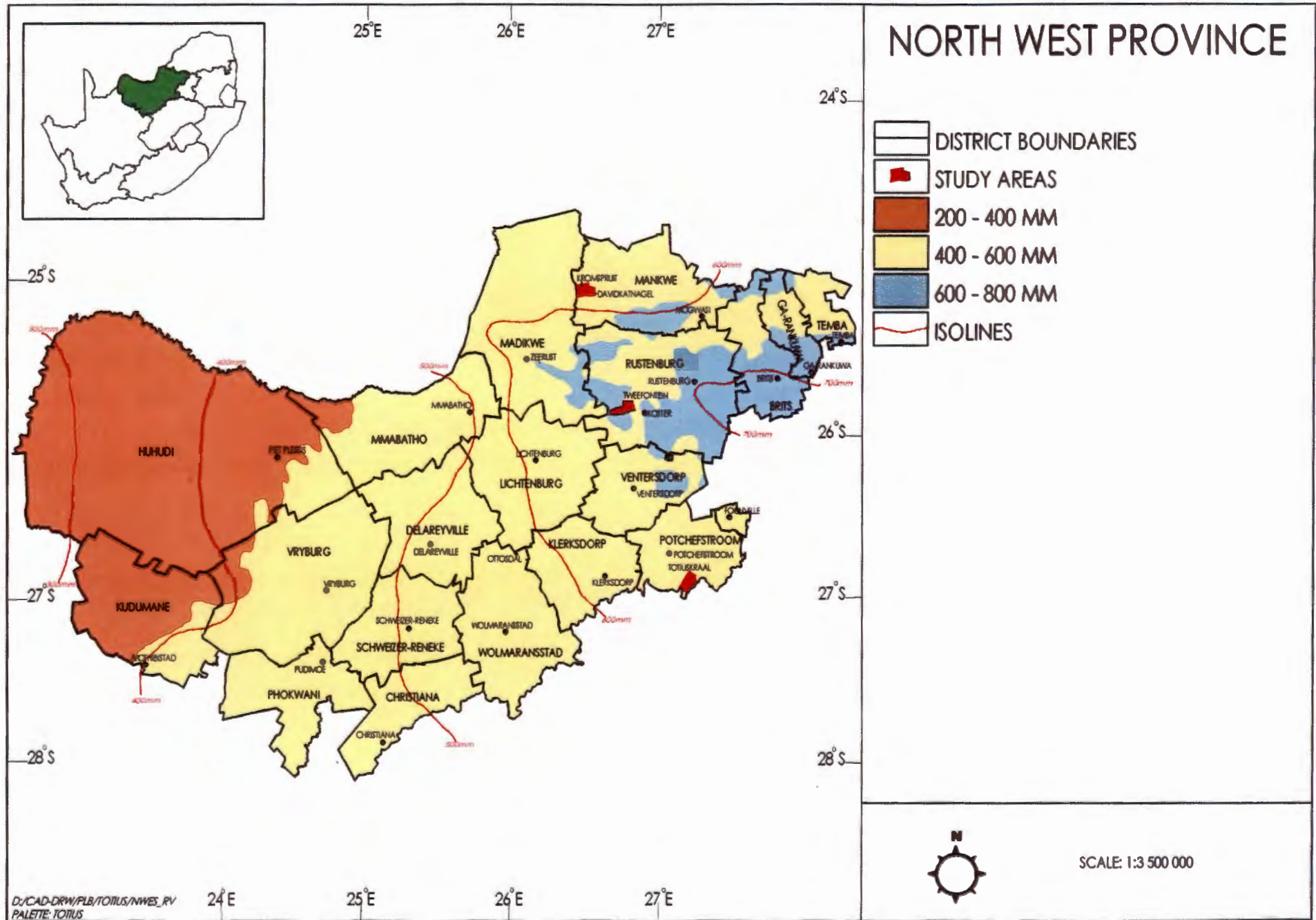
metereological station and the Botataboomen station (34km WSW from Kromspruit). Botataboomen and Goudini data were combined (filling in the blank months of Goudini with the available Botataboomen information) and averaged. Lindleyspoort, 24km ESE from Davidskatnagel was combined with Goudini information. Temperature averages were calculated from information of the Marico irrigation station, 47 km SW of Kromspruit and Davidskatnagel and the Brits Agricultural station 40 km ESE of Kromspruit and Davidskatnagel.

3.7 Concluding remarks

The study areas are all situated within the Summer Rainfall Area of South Africa. Rainfall occurs mainly between October and March with peaks during December and January. Except for the study area at Tweefontein and Totiuskraal, the other two areas had less rain during the duration of the study period than the long-term average. Comparing the rainfall patterns of each year, a rainfall peak is evident in either November/January or March (see Fig. 5.2, Chapter 5; Fig. 6.2, Chapter 6; Fig. 7.2, Chapter 7 and Fig. 8.2, Chapter 8), which may well influence pasture management strategies.

In conclusion, a brief and general summary of the similarities and differences between the four study areas is presented. Similarities between the four study areas include the presence of quartzite and shale (although no shale occurs at Tweefontein) among other rocks, a sandy-clay-loam texture throughout and a clay content of above 22%. Tweefontein and Totiuskraal have similar altitudes which differs from Kromspruit and Davidskatnagel (945 m and 960 m above sea level, respectively). The geology of Kromspruit and Davidskatnagel is similar and differs for the greater part from that of Totiuskraal and Tweefontein. Tweefontein and Totiuskraal's geology also differs. Red soils occurred in all the study areas, except Davidskatnagel. Kromspruit was partly a red soil and partly a dark coloured soil. Not one of the study areas has a slope facing in the same direction. Only Tweefontein had well drained soils. Tweefontein, Kromspruit and Davidskatnagel have pH-values of 7, but Totiuskraal had acid soils. Only Tweefontein had a cover of unpalatable, perennial grass species, the other study areas were predominantly covered with annual species.

Figure 3.2: The rainfall isolines of the North West Province, South Africa together with the general areas of specific rainfall (supplied by Dept. of Geography and Environmental Study: Cartographic and GIS Services)



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Chapter 4. Materials and methods

The sequence of materials and methods applied to the study areas are discussed under the headings Restoration Treatment, Field Sampling, Soil Seedbank Analysis, Germination Tests & Seedling Survival and Data Analysis. The actual chronological sequence of these activities was Restoration Treatment, Germination Tests, Field Sampling, Soil Seedbank Analysis, Seedling Survival and Data Analysis. Field Sampling (Table 4.1) and Data Analysis were repeated. The methods are repeated in Chapters 5 – 8 for the sake of publishing.

Table 4.1: The type and timing of the different measurements at the study areas [f¹ = frequency (%), d² = density (plants/m²), g³ = growth stage (seedling, vegetative or reproductive stages) and s⁴ = soil seed bank analysis]

	1995/1996	1996/1997	1997/1998	1998/1999	1999/2000
Twefontein	f ¹ , d ²	f, d, g ³	s ⁴	f, d, g	f, d, g
Totiuskraal	f, d, g	f	s	f, d	f, d
Kromspruit		f	f, d, g, s	f, d, g	
Davidskatnagel		f	f, d, g, s	f, d	

4.1 Restoration treatment

Restoration treatment consisted of bush clearing (at Kromspruit), exclosing the study areas, rip plough cultivation and oversowing. In the case of Kromspruit a total area of 7500 m² was cleared of bushes with the help of women from the Davidskatnagel community in order to reduce competition. No bush clearing occurred at Twefontein, Totiuskraal or Davidskatnagel because none of them were bush encroached. Three to four stranded barbed wire fences were erected around the study areas of Twefontein, Totiuskraal and Kromspruit. The fences exclosed large grazers, e.g. cattle, to allow the plants from the oversown seed to establish properly. Davidskatnagel's study area was fenced with wire-netting, to exclude both cattle and goats. Each study area had a gate. Twefontein was 6133 m² in area, whereas Totiuskraal and Davidskatnagel was 0.05 ha and 1 ha, respectively.

All four study areas were rip ploughed using a tractor and a rip plough (one to eight tines). The implements available from the farmers and community members were used. At Tweefontein, the rip rows were 200 mm deep and 800 mm apart in two directions to ensure that as many *Cymbopogon plurinodis* tufts as possible were backploughed and uprooted. The rip furrows were semi-perpendicular to the slope to lessen erosion. At Totiuskraal, four separate areas within the study area were rip ploughed to a depth of 70 mm and the furrows 200 mm apart, backploughing the mostly annual grass species. The furrows were perpendicular to the slope to lessen erosion. At Kromspruit, the furrows were parallel with the slope, 150 mm deep and 800 mm apart. At Davidskatnagel, the furrows were 150 mm deep and 800 mm apart. No slope existed, but the furrows stretched from east to west.

Sub-plots were subsequently laid out. At Tweefontein, the total study area was divided into 25 sub-plots. 24 of the sub-plots were 30 m x 7 m in size. 12 of the 24 sub-plots were oversown with mixtures of enhanced seed and 12 with mixtures of untreated seed (Table 5.1 for detail, Chapter 5). The distinction between sub-plots oversown with enhanced seed and those with untreated seed was to establish whether enhanced seed is the better seed type for restoration purposes. The 25th sub-plot (three times the size of a sub-plot) was not oversown and served as a control for rip plough treatment not combined with oversowing. The rip ploughed control plot layed perpendicular between the sub-plots oversown with enhanced and untreated seed. Another control plot existed outside the study area, and was not rip ploughed or oversown, but grazed. This control plot was chosen adjacent to the study area and of a size in which five quadrats and 100 points could be surveyed. This control plot contained the unrestored vegetation that was compared with the restored area. The same type of layout applies to all the other control plots. At Totiuskraal, the four plots were subdivided into a total of 10 sub-plots. The size of each sub-plot was 50 x 10 m. Five of these sub-plots were oversown with mixtures of enhanced seed and five with mixtures of untreated seed (Table 6.1 for detail, Chapter 6). A control plot was situated outside the fenced area. At Kromspruit, 21 sub-plots formed the study area, with one serving as a control plot. The size of each sub-plot was 70 m x 5 m. The 20 sub-plots were divided into 10 sub-plots oversown with mixtures of enhanced seed and 10 oversown with mixtures of untreated seed (Table 7.1 for detail, Chapter 7). Five of the sub-plots oversown with enhanced seed had 50% more seed to test for added competition factor. A control plot existed outside the study area, but in an area also cleared of bushes. At Davidskatnagel, the total study

area was divided into 11 sub-plots. Each sub-plot was 100 m x 5 m. Five of the sub-plots were oversown with mixtures of enhanced seed and five with untreated seed (Table 8.1, Chapter 8). The difference between plants from enhanced and untreated seed was examined. One of the sub-plots was a control that was only rip ploughed to examine the effect of rip ploughing not combined with oversowing. Another control plot outside the enclosure was grazed, to serve as a benchmark for unrestored vegetation. The choice of grass species was determined by the invasive nature of the species (in contrast to *Cynodon dactylon*) and the palatability of the species (in contrast to *Eragrostis curvula*). Another determinant of species choice was the availability of seed (in contrast to *Setaria sphacelata*).

4.2 Field sampling

The original grass composition was noted prior to any restoration treatment. Vegetation surveys were carried out over a period of four years during February or March of the growing seasons (Table 4.1 for detail). In each sub-plot the frequency of the grasses was determined by means of the wheelpoint with the 100 nearest plants recorded on the rows where seed was oversown (Tidmarsh & Havenga, 1955). If no plant occurred in a radius of 300 mm from the point, the point was noted as bare ground. The frequency surveys is a measure of the species composition of the study area. Data of subsequent years are used to detect any change in the species composition as well as their contribution to the overall species composition.

The density of each species was determined using a randomly placed quadrat (1 x 1 m) (Barbour *et al.*, 1987) in each sub-plot. Three replicate quadrats per sub-plot were monitored. In the quadrat, the density of the following three plant growth stages was noted: established seedling, vegetative mature plant (having more than one tiller protruding from the ground), and reproductive plant (clearly bearing reproductive organs or the remains of those). In the case of *C. gayana*, a vegetative reproductive plant, forming stolons, each daughter plant was counted as an established seedling.



Figure 4.1: A wheelpoint was used to measure the percentage composition of the grass species in each sub-plot.

4.3 Soil seedbank analysis

During January - April 1998 three soil cores per sub-plot were taken to a depth of 200 mm with a soil auger ($\approx 1005.7 \text{ cm}^3 \times 3$) (Du Toit & Alard, 1995; Navie *et al.*, 1996). These samples were used for the soil seedbank analysis. Reasons for soil seedbank analysis are given in section 2.6.2 (Chapter 2). Soil samples were placed in paper bags and taken back to the greenhouse, spread out and air-dried (Du Toit & Alard, 1995). The three samples from each sub-plot were combined and placed into the seed trays (200 x 300 x 80 mm) used for the analysis. Trays for every study area were kept in chronological order in a greenhouse at the Potchefstroom University of Christian Higher Education with a day temperature of 28 °C and a 20 °C night temperature (Figure 4.2). Water was applied daily to keep the soil moist (Du Toit & Alard, 1995; Schrautzer *et al.*, 1996) and the soil was disturbed at intervals to encourage germination of the seeds (see Section 9.11 for comments on the applicability of this procedure). Germinating plant species (the first appearance of the plumule and radicle according to Weinbrenn, 1946) were counted weekly (Young *et al.*, 1987) from 23 October 1998 to 25 March 1999 (153 days) resulting in figures for the immediate field germination capacity. It excludes the viable seed with long dormancy and impermeable tegmentum (Bertiller, 1996), leaving approximately 1.9% of seeds in the soil seed bank (O'Connor & Everson, 1997). Seeds that did not germinate were not

removed from the soil after a period of 153 days (extending the suggested 90-119 days according to Schrautzer *et al.*, 1996). Germination is considered to be an adequate method of quantifying seed in the seed bank (Leck & Simpson, 1995). Where a species was represented by more than one individual, all but one were removed from the trays till it was sufficiently mature to be identified, to minimise the competition factor (Navie *et al.*, 1996). The structure of the soil seed bank is described as the seed density, the number of seeds, the species represented as well as the dominant species. The data were compared to the standing vegetation in every study area. According to literature examined (Akinola *et al.*, 1998; Lyaruu, 1999), soil seed banks seldom correspond to the standing vegetation (see section 2.6.2, paragraph 7 onwards, Chapter 2 for reasons).

Seedling density of the soil seedbank analysis per 1 x 1 x 0.02 m was calculated as follows:

Three samples of >1005.7 cm³ soil adds up to 4800 cm³ (volume of soil contained in 300 x 200 x 80 mm containers). This is converted to 1 x 1 x 0.02 m, as a measurement of the field density.

For example, 73 seedlings germinated from a seed tray. Converting the amount of seedlings/cm³ to the amount of seedlings/1 x 1 x 0.02 m:

$$\frac{73 \text{ seedlings} \times 20\,000}{4800 \text{ cm}^3} = 304.17 \text{ seedlings}/1 \times 1 \times 0.02 \text{ m} \dots\dots\dots 4.1$$

A second set of soil samples was analysed chemically to provide environmental information. In the beginning of the project, pH-values were determined in water solutions. The last soil analysis was done in KCl solution. pH determined in a KCl solution is more accurate and approximately one unit lower than pH determined in H₂O. All pH-values in the dissertation are given as water determined values for the sake of uniformity (Van Rensburg¹, 2000, February., personal communication).

¹ ✉ Van Rensburg, L., School of Environmental Sciences and Development, Private Bag x 6001, PU for CHE, Potchefstroom, 2520, ☎ + 27 18 299 2500



Figure 4.2: The arrangement of the seed trays used during the soil seed bank analysis. Each tray contains the three combined soil samples of a sub-plot with the plant species that germinated in each of them.

4.4 Germination tests and seedling survival rates

The viability of the seed of each oversown species (the same batch of seed that was used in the oversowing treatment) was determined by germination tests carried out under controlled laboratory conditions. The reasons for the germination tests were to determine the quality of the seed used in the restoration treatment (see section 2.5, Chapter 2). Ten seeds per species were placed in containers, 10 ml of distilled water was added to each, and the containers were sealed to avoid moisture loss. The trials were carried out at 25 °C for 28 days in a Gallenkamp Plus II Incubator (Monitoring and Control Laboratories²). Laboratory conditions are optimal for germination, although valid critic is raised that the laboratory conditions are also ideal for fungus growth. Containers are sterilised, however, with 95% alcohol to control fungus infection. The number of seeds that germinated was noted as the viability of the given species (According to Mr. L. Reynecke, see section 9.11 for comment, Chapter 9). According to law (SA, 1995:174) and the International Seed Testing

⁷ ☒ Monitoring and Control Laboratories (Pty) Ltd. Box 890226, Lyndhurst 2106, ☎ (011) 483 3149 (o), (011) 483 2146 (f).

⁸ ☒ International Seed Testing Association, Secretariat, P.O. Box 412, 8046 Zurich CH-Switzerland, ☎ +41 1 377 60 00, Fax +41 1 377 60 01, e-mail istach@iprolink.ch

(ISTA³) the minimum germination rate for grass seed must be 20%. The results of the laboratory viability test were compared to the seedling survival rates as part of density data, in the restored pasture.

A specific procedure was followed to compare the number of seeds sown into the sub-plots, the number of viable seed per mass as determined under laboratory conditions and the number of surviving seedlings in the field (see calculations 4.1 to 4.3). This comparison is an indication of the overall survival of the sown grass species in the establishing years (1995-1997). This, in turn, has economic implications with regard to the amount of seed to be purchased for future restoration projects. Apart from the economic implications, the number of surviving seedlings in the field is an indication of the expected sustainability of a particular species over the medium term. Calculation of the number of seeds consisted of the number of seeds in 1 gram (Table 4.2) multiplied with the kilograms of seeds sown into each sub-plot (see Chapters 5 - 8). The number of plants were then divided by the amount of seeds sown into each sub-plot and multiplied by 100 to give the percentage of seedlings that survived, for example:

A total of 32 g of *D. eriantha* seeds was sown into a sub-plot (210 m²). There are 30 600 seeds in 32 g of *D. eriantha* (Table 4.2, calculation 4.1). From these 30 600 seeds sown in 210 m², an average of 15.7 plants established in 1 m².

$$\begin{aligned}
 &32 \text{ g} \times 0.03 \text{ g} \text{ (= impurity conversion factor)} = 0.8 \text{ g (actual weight of impurities)} \\
 &32 \text{ g} - 0.8 \text{ g} = 31.2 \text{ g (actual weight of grass sown)} \\
 &31.2 \text{ g} \times 980.8 \text{ seeds/g} \\
 &= 30\,600 \text{ seeds sown in } 210 \text{ m}^2 \dots\dots\dots 4.2
 \end{aligned}$$

$$\begin{aligned}
 &15.7 \text{ plants established in } 1 \text{ m}^2 \\
 &\text{Viable seeds: } 30\,600 \text{ seeds}/210\text{m}^2 \\
 &= 145.7 \text{ seeds/m}^2 \dots\dots\dots 4.3
 \end{aligned}$$

$$\begin{aligned}
 &(15.7/145.7) \times 100 = 10.8\% \text{ field germination rate of } D. \text{ eriantha} \\
 &\text{in this specific treatment} \dots\dots\dots 4.4
 \end{aligned}$$

No allowance was made for seed or seedlings from *in situ* plants, nor for seed imported by the wind.

Table 4.2. The number of seeds in one gram of each of the sown-in grass species used at the restoration study areas

	Untreated seed/gram	Enhanced seed/gram
<i>Chloris gayana</i>	3777.8	645.9
<i>Digitaria eriantha</i>	2654.6	980.8
<i>Panicum maximum</i>	1994.4	546.3
<i>Anthephora pubescens</i>	not available at the time	27.5
<i>Cenchrus ciliaris</i>	399	104.8

4.5 Data analysis

Statistical parameters include the mean or central tendency of the variable. The larger the sample size, the more reliable its mean. The larger the variation of data values, the less reliable the mean in its description of the data (Statsoft Inc.⁴, 1999). The variance of a population of values is the square of the standard deviation of grouped data and is a parameter of the spreading, symmetry and kurtosis of the data. The standard deviation is the deviation of each value from the mean of the data, while the standard error describes the deviation of the standard deviation from the mean of the data (Steyn *et al.*, 1995). The calculation of the averages for the frequency and density of the species in the restored sub-plots can be explained as follows:

A given number of grams of grass seed were sown in a given number of hectares (without adjustments required for the mixing of different seed). Impurity values for each number of grams were subtracted, resulting in the grams of potential viable seed (according to ISTA procedures, see p. 66). The number of seeds per gram was calculated, to keep track between the number of seeds sown-in and the number of plants surviving after the first season.

The following data analysis techniques indicated the significant differences, gradients and correlation of quantitative data sets.

The quantitative data was analyzed statistically using the ANOVA/MANOVA technique in the STATISTICA for Windows (StatSoft, Inc., 1999) computer program. The purpose was to find significant differences between the means of a variable by comparing that variable's variances. Results were considered

⁴ StatSoft Inc., 2300 East 14th Street, Tulsa, OK 74104, ☎ (918) 749 1119 (o), (918) 749 2217 (f), e-mail: info@statsoft.com

statistically significant if $p < 0.05$, except where otherwise indicated. Using multivariate data analysis techniques (Hill, 1979), the change of species composition over time was determined by trajectories on a gradient. Gradient analysis was conducted using the Integrated System for Plant Dynamics (ISPD) computer package (Bosch *et al.*, 1992).

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Chapter 5. The population dynamics of grass species used in restoration treatments in a *Cymbopogon plurinodis* dominated pasture in North West Province in South Africa

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² ✉ Journal of Arid Environments, Academic Press Editorial Office, Block 2A, Westbrook Centre, Milton Road, Cambridge CB4 1YG, U.K.

5.1 Abstract

Natural succession in degraded areas or areas dominated by a dense, unpalatable grass sward, such as *Cymbopogon plurinodis*, can be restored by a rip plough cultivation method combined with the oversowing of perennial climax grass mixtures. Different mixtures of treated (enhanced) and untreated caryopses of *Digitaria eriantha*, *Chloris gayana*, *Cenchrus ciliaris*, *Panicum maximum* and *Anthephora pubescens* were oversown into part of a semi-arid pasture of undesirable composition. The successful enrichment of natural pastures by supplementary seeding is used as a partial test of the plough cultivation restoration treatment. The degree in which the soil seedbank represents the standing grass composition was examined. Variance and multivariate data analyses were performed. The most suitable grass mixture for the 25% sandy-clay-loam soil type with an average short-term rainfall of 580 mm/yr. and a pH of 7 to 8 was containing *C. gayana* (untreated), *D. eriantha* (enhanced) and *P. maximum* (enhanced). *A. pubescens* were present in the seedling, vegetative and reproductive stages and is thus a species considered for addition to the mixture. Species abundance over the long-term was determined with frequency and density measurements. Frequency and density of *C. gayana*, *P. maximum* and *A. pubescens* decreased during 1995-1999, while *D. eriantha* and *C. ciliaris* increased. 27 species resulted from the 232 seedlings that germinated from the soil seedbank analysis. The trend in the soil seedbank analysis corresponds with findings presented in the current literature. The rip plough cultivation method had negative influence on the dominant, unpalatable grass *C. plurinodis*, but had a positive effect on the establishment of species such as *Setaria sphacelata*, *Eragrostis curvula* and *Themeda triandra*. A restorative or successional gradient exists on the first ordination axis, with the vegetation composition changing from one dominated by *C. plurinodis* in 1995 to one dominated by *C. gayana* – *C. ciliaris* in 1996 and then to a *D. eriantha* dominated sward in 1999. The grass species richness increased from 13 to 24 species. The conclusion drawn is that unpalatable sward composition can be restored to a palatable composition by a rip plough cultivation method combined with the oversowing of specific grass mixtures.

Keywords: restoration ecology, grassland, soil seedbank assessment, rip plough cultivation, oversowing, DCA ordination.

5.2 Introduction

South Africa produces a net surplus of agricultural products even though the natural resources of the land are degraded. In addition, the land is often ravished by droughts (De Villiers, 1994). Degradation involves reduction of both vegetation cover and density and results in the formation of denuded patches (Bosch, 1989; Bosch & Kellner, 1991; Kellner & Bosch, 1992). Degradation leads to loss of topsoil through erosion, which in turn increases pressure on marginal land for the pasturing of livestock. Another type of degradation is the encroachment or invasion of undesirable woody or herbaceous species (Smit *et al.*, 1996). The degraded pastures usually contain species of poor ecological status, in other words species which are relatively unpalatable to animals due to short life span and low production potential (Van Oudtshoorn, 1999). The economical and ecological costs due to the degradation of land and the attempts to replenish these resources amount to thousands of dollars yearly (De Villiers, 1994; Choi & Wali, 1999).

Whenever natural pastures degrade, the amount of livestock such pastures can sustain diminishes. Jones & Mott (1980) stated that an attempt to improve (restore) or sustain the floristic composition of pastures should be preceded by identification of the processes controlling the change in vegetation cover. One of the ways of doing so is to employ a demographic study of the major constituent species. From population dynamic studies the sustainability of a pasture can be identified and management practices can be adjusted accordingly (Jones & Mott, 1980).

The restoration of bio-diversity or productivity of a degraded or disturbed natural pasture entails either withdrawal of livestock (passive management) or different active interventions, such as cultivation and oversowing (Milton & Dean, 1995). Seeds used in oversowing treatments can either be enhanced or untreated. The enhancement (pelleting or coating) of the seed (Siebert³) is the encapsulation of the caryopsis with soil or fertiliser (Tainton, 1981, see Section 2.3). The aims of enhancement would determine the specific procedure and materials used. The enhancement may be directed 1) at improving the moisture regime surrounding the seed, 2) at providing a source of plant nutrients in close contact with the rootlet of the germinating seed, and/or 3) at protecting the seed against

³ ☒ Siebert Seed Consultants, Nieuwestraat 58, Potchefstroom, 2520, ☎ 083 300 6938.

predation (Tainton, 1981). The enhancement has a ballistic advantage, preventing the seeds from being blown away after sowing (T.S. Siebert, 1999, February personal communication). The basic material for enhancement is usually either lime, superphosphate or rock phosphate. An essential ingredient is an adhesive such as carboxy methylcellulose (CMC) or gum arabic (B. Lever, Advance Seed⁴, 1999, February personal communication; Tainton, 1981). The enhancement of seed is a relatively new concept in South Africa, especially with grass seeds used in the establishment of cultivated pastures or restoration of degraded rangelands.

Most population dynamics studies investigate the turnover of a species of either the shoot, vegetative or tiller/seedling stages (Falinska, 1991; Shackleton, 1991; Witkowski & Liston, 1997; Morgan, 1998; O'Connor & Everson, 1998; Meyer & Schmid, 1999). Few studies, however, simultaneously compare the increase or decrease of the tiller/seedling, vegetative and reproductive stages of plant species (Desmet *et al.*, 1996). Tilman *et al.* (1996) state that the more diverse a community, the more sustainable it is, but do not mention the parameters for population sustainability. Representation of a population in the seedling, vegetative and reproductive growth stage in February-March, as used in this study, could be such a sustainability parameter. Another aspect to keep in mind is the structure of the already available soil seed bank (Van der Valk & Pederson, 1989; Akinola *et al.*, 1998; Falinska, 1999; Lyaruu, 1999) as the soil seed bank would influence the establishment of the seeds oversown during the restoration process. The structure of the soil seed bank includes the density of each species, the number and type of species, and the dominant species in the soil seed bank.

The main aim of this study is to use five grass species in aiding restoration of part of a degraded pasture dominated previously by the dense, unpalatable, big tufted perennial grass *Cymbopogon plurinodis* (narrow-leafed turpentine grass). The increase of the species richness of the grasses, as well as the improvement of the vegetation condition was evaluated. The seed used in the oversowing treatment includes both enhanced and untreated seeds of *Digitaria eriantha* (common finger grass), *Anthephora pubescens* (wool grass, only enhanced seed

⁴ ☒ Advance Seed, P.O. Box 414, Krugersdorp, 1710, South Africa, ☎ + 27 11 762 5261 (o), + 27 11 762 4111 (f).

was available at the time), *Cenchrus ciliaris* (foxtail buffalo grass), *Chloris gayana* (Rhodes grass) and *Panicum maximum* (guinea grass).

5.3 Materials and methods

5.3.1 Study area

The study area (Fig. 5.3) is situated on Tweefontein, a commercially managed farm near Koster (26°53' S, 27°13' E) in the North West Province (South Africa). The farm is situated within the Grassland Biome (Rutherford & Westfall, 1994) and classified as the Bankenveld (A61) veld-type by Acocks (1988). This summer rainfall area stretches over the transition of the climatic climax grasslands into the Northwest sour bush velds (Tainton, 1981). The long-term average annual rainfall is 491 mm/yr. The average annual rainfall recorded in the area between 1995-1997, the year of restoration application and the subsequent years of the establishment of the grass species, was above the long-term average, namely 783 mm/yr. (Fig. 5.1). During the rainy summer season, rainfall occurred on approximately 6.7 days of each month. The rainfall pattern is typical for Summer Rainfall Regions, increasing from September to peak in December (1995), January (1997) and March (1995 and 1997). The rainfall of March 1996, however, was exceptionally low (Fig. 5.1). The minimum temperature for the period 1995 to 1999 was 0 °C. The maximum temperature for the period 1995 to 1999 was 37 °C. Average temperatures are depicted in Figure 5.2. Temperature information from the Klippan weather station, situated 33 km SSE of the study area (1995-1999), and rainfall information from the Grootpan (1995-1999) and Mapperley weather stations (20 years ending 1950) were used. AgroMet, Potchefstroom⁴ supplied the information.

The study area slopes 7° towards the north and north east (Schulze *et al.*, 1997). The geology of the area includes quartzites and shales of the Pretoria Group, Transvaal Supergroup (Land Type Survey Staff, 1984a). According to the land type classification (Land Type Survey Staff, 1984a, Schulze *et al.*, 1997), the study area is situated in the Ae59d-landtype (see Section 3.2.3, Chapter 3). The soil form is Arcadia, partly overlain by alluvial Hutton sand. According to the analysis of soil taken at a depth of 300 mm, the soil texture has a high silt

⁴ ☒ AgroMet Potchefstroom, Institute for Soil, Climate and Water, P/b X 1251, Potchefstroom, 2520

content with a clay percentage of 25% (Department of Conservation and Environment: Geology Section⁶).

The vegetation was dominated by the large, tufted, unpalatable grass *C. plurinodis*; a species of poor ecological status (Increaser I according to Bosch, 1987) that contains bitter volatile oils and is therefore avoided by grazers. *C. plurinodis* shows vigorous growth and is a highly competitive species, increasing especially in underutilized pastures.

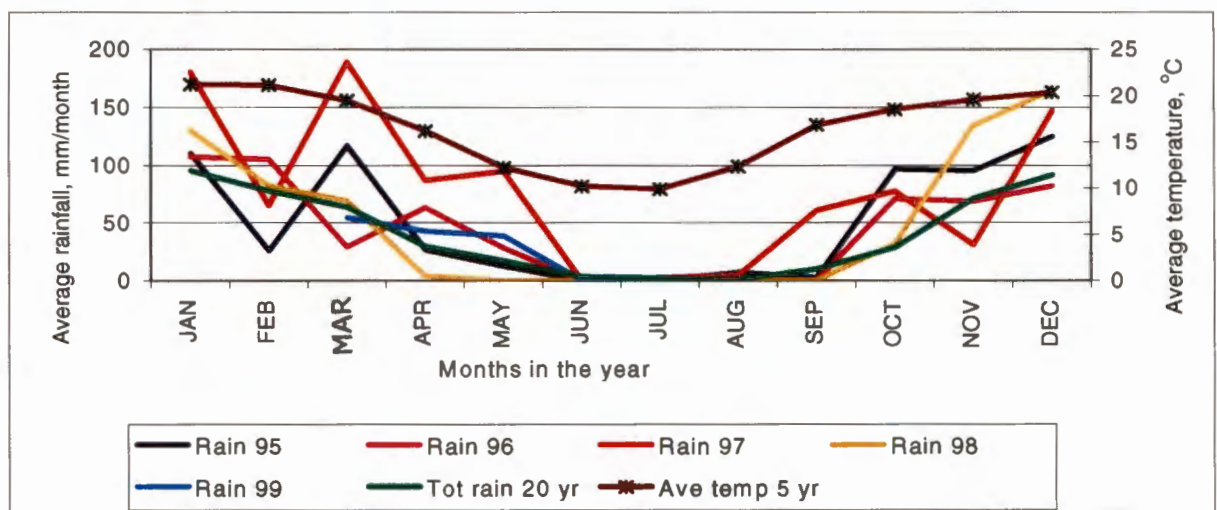


Figure 5.1: The average monthly long-term (20 yrs.) and short-term (1995-1999) rainfall and temperature (°C) for the Tweefontein study area.

5.3.2 Restoration treatment

The restoration process entailed backploughing of *C. plurinodis* with a rip plough cultivation method (Tainton, 1981; Van der Merwe, 1997). The rip rows were 200 mm deep and 800 mm apart in two directions to ensure that as many *C. plurinodis* tufts as possible were uprooted (Fig. 5.2). Seed of palatable, perennial grasses such as *D. eriantha*, *A. pubescens*, *C. ciliaris*, *C. gayana* and *P. maximum* (the oversown grasses are native to the area, but *C. gayana* is naturalised from India) was oversown into the furrows by hand, and slightly

⁶ ☒ Department of Conservation and Environment: Geology, P/bag X 804, Potchefstroom, 2520.




covered with a soil layer. The oversowing treatment was carried out at the start of the rain season in November 1995. The total study area of 6133 m² was divided into 25 sub-plots of 30 m x 7 m in size, of which 24 sub-plots were oversown with the mixture of the enhanced (12 plots) and untreated seed (12 plots).

The 12 sub-plots oversown with enhanced seed were divided into two sets of six sub-plots oversown with the mixtures given in Table 5.1. The same applies for the sub-plots oversown with untreated seed. In the tables and figures the sub-plots are numbered from one to six for both the enhanced and untreated seed (take note of the titles to determine whether the figure deals with enhanced or untreated seed). One sub-plot has not been oversown and served as a control. This sub-plot was divided in three smaller areas. The average amount of seeds in each mixture oversown into each of the sub-plots is depicted in Table 5.1. The study area was fenced to keep out all large herbivores after the restoration application. Another control plot outside the fenced study area was neither rip ploughed nor oversown. This plot, which was still grazed, was selected to determine which species would establish by natural succession in the restored area after the restoration procedure.



Figure 5.2: The study area just after the rip plough cultivation method and before the oversowing treatment was applied.

TWEEFONTEIN FARM

-  MAIN ROADS
-  RAILWAY LINES
-  STUDY AREA



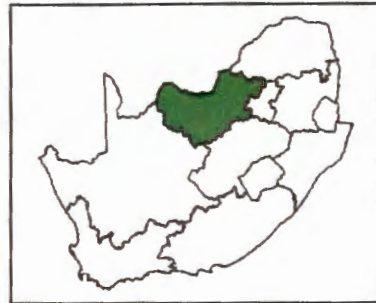
SCALE 1:230

26 45' E

25 47' S

25 47' S

26 45' E



JAN: C:\TWEEFNTN
PALETTE: TOTUS

Figure 5.1: The farm Tweefontein where the use of rip ploughing and oversowing as restoration applications were investigated (supplied by Dept. of Geography and Environmental Study; Cartographic and GIS Services)

Table 5.1: The average weight (in kilograms/ha) of the seed oversown in different seed mixtures and the average number of seeds per gram (in brackets) at the Tweefontein study area, North West Province, South Africa (*- no untreated seed available). Abbreviations of species names will be used in subsequent figures. Enhanced seed were oversown in two replicates of six sub-plots. Ditto for the untreated seed

Species	Treatment	Sub-plot 1 kg (seeds/gm)	Sub-plot 2 kg (seeds/gm)	Sub-plot 3 kg (seeds/gm)	Sub-plot 4 kg (seeds/gm)	Sub-plot 5 kg (seeds/gm)	Sub-plot 6 kg (seeds/gm)
<i>Digitaria eriantha</i> (D.eri)	Enhanced	1.5 (981)	3.1	3.1	1.5	1.5	1.5
<i>Cenchrus ciliaris</i> (C.cil)	Enhanced	2.5 (105)			2.5		
<i>Chloris gayana</i> (C.gay)	Enhanced		3.1 (646)		1.5		
<i>Antheophora pubescens</i> (A.pub)	Enhanced					2.5 (28)	2.5
<i>Panicum maximum</i> (P.max)	Enhanced			3.1 (546)	1.5		1.5
		Sub-plot 1	Sub-plot 2	Sub-plot 3	Sub-plot 4	Sub-plot 5	Sub-plot 6
D.eri	Untreated	1 (2655)	1.5	1.5	0.8	0.8	0.8
C.cil	Untreated	1.3 (399)			1.2		
C.gay	Untreated		2 (3778)		0.8		
A.pub	Untreated					*	*
P.max	Untreated			2 (1994)	0.8		0.8

5.3.3 Field sampling

Vegetation surveys were carried out over a period of four years during February or March of the growing seasons 1995/1996, 1996/1997 and 1998/1999. Surveys were conducted in 1999/2000 but is not included in this study. In each sub-plot the frequency of the grasses was determined by means of the wheelpoint method with the 100 nearest plants recorded on the rows where seed was oversown (Tidmarsh & Havenga, 1955).

The density of each species was determined using a randomly placed quadrat (1 x 1 m) (Barbour *et al.*, 1987) in each sub-plot. Three replicate quadrats per sub-plot were monitored. In the quadrat, the density of the following three plant growth stages were noted: established seedling, vegetative mature plant (having more than one tiller protruding from the ground), and reproductive plant (clearly bearing reproductive organs or the remains of those). In the case of *C. gayana*, a vegetative, reproductive plant forming stolons, each daughter plant was counted as an established seedling.

5.3.4 Soil seed bank analysis

Soil samples were collected for the soil seed bank analysis in the summer period of 1998/1999. Three soil samples per sub-plot were collected with a soil auger ($\approx 1006 \text{ cm}^3$, Du Toit & Alard, 1995) and allowed to air dry for two weeks. The three samples of each sub-plot were combined ($\approx 3017 \text{ cm}^3$) in a 300 x 200 x 80 mm (4800 cm^3) seed tray. Tsuyuzaki & Kanda (1996) used a 100 cm^3 soil sample in each 1 x 1 m plot. Seed germination rate was determined by the number of seedlings that germinated (Tsuyuzaki & Kanda, 1996). The analysis proceeded in a greenhouse where the temperature cycled from 28 °C day to 20 °C night temperature. The soil was kept moist (Du Toit & Alard, 1995; Schrautzer *et al.*, 1996). The species were allowed to germinate (first appearance of the radicle and the plumule according to Weinbrenn, 1946) and left until identification was possible. Where two or more of the same species germinated, all but one specimen was removed to reduce the competition among seedlings for nutrients and water. Identified species were also removed for the same reason, and a precaution against seed contamination. The results of the soil seed bank analysis were noted and compared with the standing grasses of the study area. A period of 150 days is sufficient for only 2% of seed to remain in the soil (O'Connor & Everson, 1998).

Seedling density of the soil seed bank analysis per 1 x 1 m x 0.02 m was calculated as follows:

Three samples of $>1006 \text{ cm}^3$ soil adds up to 4800 cm^3 (amount of soil that fits into 300 mm x 200 mm x 80 mm containers). That is converted to 1 x 1 m x 0.02 m, as a measurement of the seedling density per square meter in the field. The seed in the soil are rarely buried deeper than 2 cm and a lot of the seed only occurs in the litter layer.

For example, 73 seedlings germinated from this seed tray. Converting the amount of seedlings/cm³ to the amount of seedlings/1 x 1 m x 0.02 m (20 000 cm³ is the conversion factor):

$$\begin{aligned} & \frac{73 \text{ seedlings}/4800 \text{ cm}^3 \times 20\,000 \text{ cm}^3}{4800 \text{ cm}^3} \\ & \text{or } \frac{73 \text{ seedlings}/0.0048 \text{ m}^3 \times 0.02 \text{ m}^3}{0.0048 \text{ m}^3} \\ & = 304.17 \text{ seedlings}/0.02 \text{ m}^3 \\ & \text{or } 304.17 \text{ seedlings}/1 \text{ x } 1 \text{ m x } 0.02 \text{ m} \dots\dots\dots 5.1 \end{aligned}$$

5.3.5 Germination tests

The germination rate of the seed of each oversown species (the same batch of seed that was used in the oversowing treatment) was determined by germination tests carried out under controlled laboratory conditions (see Section 9.11, Chapter 9). Ten seeds per species were placed in containers, 10 ml of distilled water was added to each, and the containers were sealed to avoid moisture loss (see Section 9.11, Chapter 9). The trials were carried out at 25 °C for 28 days in a Gallenkamp Plus II Incubator (Monitoring and Control Laboratories⁷). The number of seeds that germinated was noted as the germination rates of the given species. According to law (SA, 1995:174) and the International Seed Testing Association (ISTA⁸) the minimum germination rate for grass seed must be 20%. The results of the laboratory germination test were compared to the seedling survival rates in the restored pasture as part of density data.

5.3.6 Data analysis

The averages of the number of seed oversown in the field, the laboratory germination rate and the survival of the seedlings in the field of the grass species; in the restored sub-plots were calculated in the following manner:

⁷ ☒ Monitoring and Control Laboratories (Pty) Ltd. Box 890226, Lyndhurst 2106, ☎ (011) 483 3149 (o), (011) 483 2146 (f).

⁸ ☒ International Seed Testing Association, Secretariat, P.O. Box 412, 8046 Zurich CH-Switzerland, ☎ +41 1 377 60 00, Fax +41 1 377 60 01, e-mail istach@iprolink.ch

Of the given weight (in grams) of grass seed oversown in a given number of hectares, a minimal amount is impurities. Per definition, subtracting these impurity values from the number of grams of seed oversown would result in the actual number of grams of pure seed (see Section 2.4, chapter 2) oversown into a sub-plot. But of this so-called pure seed, only a fraction is actually viable and this germination rate is tested under laboratory conditions. The laboratory germination rate is an indication of the possible germination of seed in the field. In the field, seeds germinate and survive at a different rate than under the optimum conditions created in a laboratory. The weight (in grams) of the seed oversown into the sub-plots was converted to the number of seeds oversown into the field so that the number of seeds oversown could be compared to the number of seedlings/m² that survived. The aim was to establish the number of seeds that actually became part of the pasture. The calculation was done in the following manner: One gram of seeds of a specific grass species was weighed and the number of seeds in that one gram counted. This procedure was repeated three times. The average number of seeds per gram was calculated for the three repetitions and was then multiplied with the weight (in grams) of each grass species oversown into the sub-plots, resulting in the number of seeds of a specific grass species oversown into each sub-plot (210 m²). The number of seeds was compared graphically with the total number of surviving seedlings in three quadrats in the field after the first season.

The quantitative data was analyzed statistically using the ANOVA/MANOVA technique in the STATISTICA for Windows (StatSoft, Inc., 1999) computer program. The purpose was to find significant differences between the means of a variable by comparing that variable's variances. Results were considered statistically significant if $p < 0.05$ except where otherwise indicated. The results for the individual sub-plots were chronologically discussed in Section 5.4.1.

Using multivariate analysis techniques, namely DECORANA (Hill, 1979) the change of species composition over time was determined by trajectories on a gradient. A DCA-ordination technique was used for the gradient analysis, conducted with the Integrated System for Plant Dynamics (ISPD) computer package (Bosch *et al.*, 1992).

5.4 Results

5.4.1 Seed viability, seedling survival and grass mixtures

The sub-plots oversown with untreated and enhanced seed differed significantly with regards to the frequency and density data (Table 5.2) and the data is non-parametric in distribution.

Table 5.2: Factor analysis (STATISTICA) in significant p-values comparing the treatments (untreated or enhanced seed) for different factors

Factor	Germination rate	Survival	Frequency	Vegetative density	Sub-plots
Treatment	0.02	0.00	0.02	0.05	0.00

The untreated seed of the grass species oversown into the sub-plots had a higher germination rate than the enhanced seed of the same species (Fig. 5.4, e.g. D.eri u = 24 versus D.eri e = 21). (No comparison is drawn for *A. pubescens* because untreated seed were not available at the time). In the field, however, the enhanced seed had the greater survival rate, except for *C. ciliaris* (Fig. 5.5, C.gay e = 12 versus C. gay u = 7).

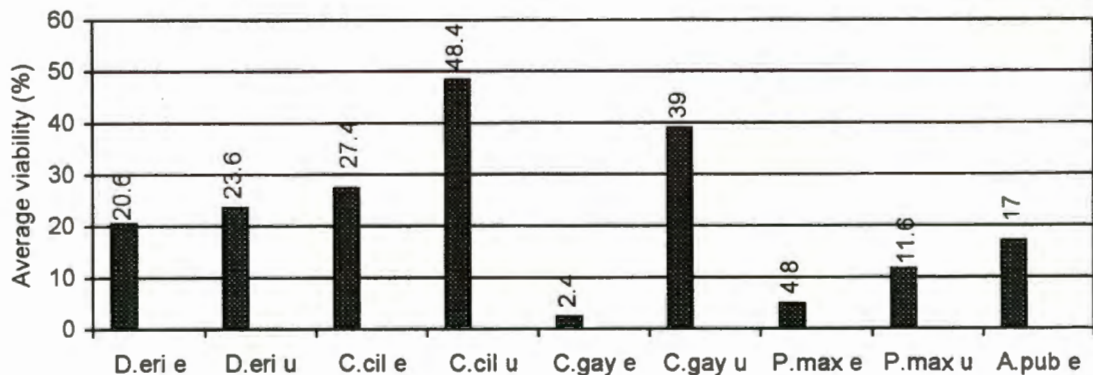


Figure 5.4: The average germination rate in the laboratory of the enhanced (e) and untreated (u) seed of the grass species oversown in the field trials at Tweefontein ($p = 0.02$). See Table 5.1 for an explanation of the abbreviations of the species.

The rainfall peaks occurred approximately 15 days before the oversowing treatment was applied, as well as on the day of sowing and the day thereafter, ensuring a better establishment of the grass species oversown in the degraded pasture (Fig. 5.2).

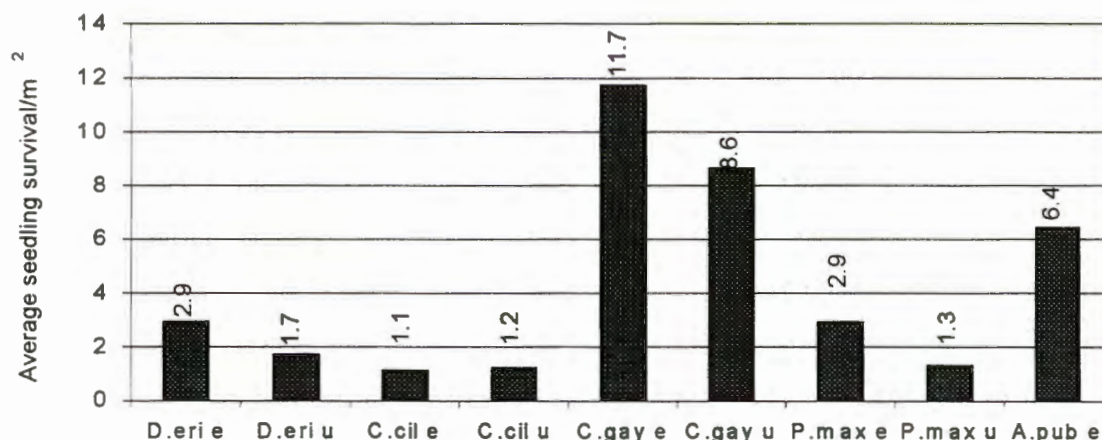


Figure 5.5: The average number of seedlings surviving from the enhanced (e) and untreated (u) seed in the field trials at Tweefontein (ripped to depth of 200 mm, $p = 0.00$). See Table.5.2 for the p-values. Seed germination rate not taken into account.

No marked correlation exists for any of the six mixtures and the number of individuals (Tab. 5.1 compared with Fig. 5.4 & 5.5). The Spearman Rank values were -0.35, -0.26, -0.05 for the number of seed oversown, the germination rate of the seed in the laboratory and the survival of the seedlings in the field, respectively. For example, in sub-plot 1, $32\text{g} - 0.03\text{g}$ (impurities) = $31.97\text{g} \times 981$ seeds of *D. eriantha* were oversown, amounting to a number of 31 363 seeds in the 210 m² of sub-plot 1. The same batch of seed has a laboratory germination rate of 21% \times 31 363 seeds = 6461 seeds that germinated. In the field only 2% of the 31 363 seeds developed to what is defined as a surviving seedling, equaling 467 seedlings of *D. eriantha* in sub-plot 1. Sub-plot 2 of the enhanced treatment is the only one in which all the constituent grass species, i.e. *D. eriantha* and *C. gayana* were present in the field (the second group in Fig. 5.6). In sub-plot 4, *C. gayana* (untreated and enhanced) and in sub-plot 1 of the

untreated seed, *A. pubescens*, occurred in the same plot with *D. eriantha*. From Fig. 5.6 it is clear that *P. maximum* seedlings did not survive in the field in the first year (1996/1997) after the restoration application.

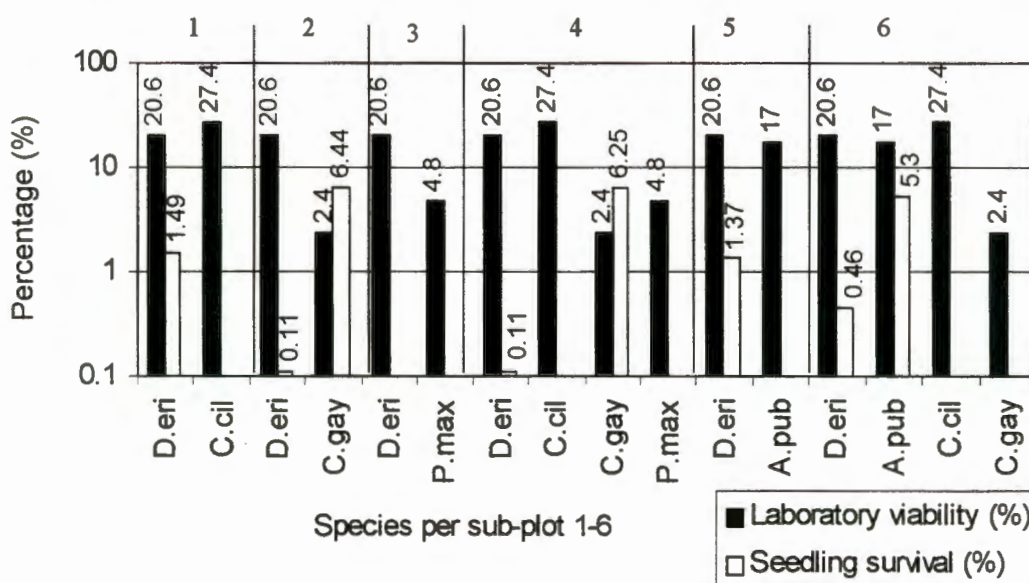


Figure 5.6: The restoration treatment where enhanced seed was used at Tweefontein: a comparison of the germination rate of the seed in the laboratory to the percentage of seedlings of mixtures used in sub-plots 1 to 6 (Table 5.1) that survived in the field in 1996. Seed germination rate taken into account.

At the time of the survey, as will be indicated later (Fig. 5.11 and 5.12), only vegetative and reproductive plants of *P. maximum* were present in the field, the probability being that the established seedlings already became vegetative in the follow up surveys. *C. ciliaris* (for the enhanced seed, Fig. 5.6, and the untreated seed, Fig 5.7) had no seedling survival in the field in all the sub-plots.

The species of both the untreated and enhanced seed mixtures did not occur in the same sub-plot (Fig. 5.7, all oversown species had a seedling survival rate of less than 1%), although *C. gayana* occurred with *D. eriantha* in the fourth sub-plot (Fig. 5.7, no. 4).

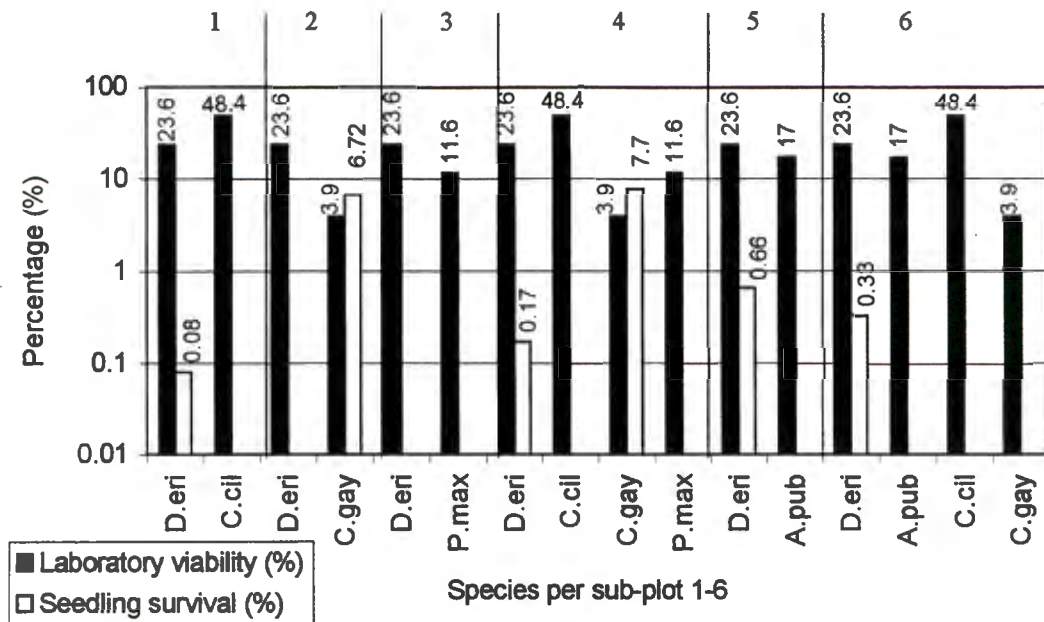


Figure 5.7. The restoration treatment where untreated seed was used in all sub-plots: a comparison of the germination rate of the seed in the laboratory to the percentage of seedlings of mixtures used in sub-plots 1 to 6 (Table 5.1) that survived in the field in 1996. Seed germination rate taken into account.

5.4.2 Frequency

The frequencies of the grasses surviving from the oversown enhanced (47%) and untreated (61%) seeds differed significantly ($p = 0.02$) from one another over the four year period (Tab. 5.2 and Fig. 5.8, C.cil e (1996) = 13 versus C.cil u (1996) = 19), except for *D. eriantha* and *P. maximum*. In the sub-plot oversown with enhanced seed, *D. eriantha* and *P. maximum* did however produce more plants than the untreated seed, even though not significantly (Fig. 5.8, D.eri e versus D.eri u). *C. ciliaris* and *C. gayana* have shown better results with the untreated seed. Both enhanced and untreated seed of *C. gayana*, *D. eriantha* and *P. maximum* had the highest frequencies of the five species oversown in (Fig. 5.8). For *C. ciliaris*, the enhanced seed showed a lower frequency than the untreated seed, corresponding with the germination rate and seedling survival data (Fig. 5.6 & 5.7). Over the period of four years (three

seasons), only the *D. eriantha* (enhanced and untreated) and *A. pubescens* (untreated) populations increased (Fig. 5.8).

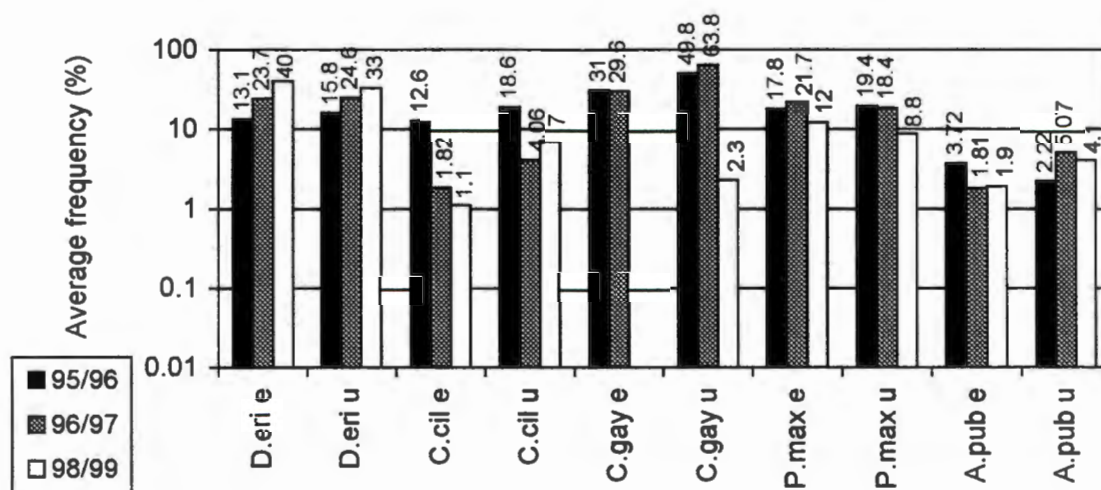


Figure 5.8: The average frequency of oversown grass species at Tweefontein over a four year period (three seasons, 1995 - 1999). Results of plants originating from enhanced (e) and untreated (u) seed of the species are shown.

The frequency of *C. ciliaris*, *C. gayana*, *P. maximum* and *A. pubescens* from the enhanced seed, decreased slightly over the study period. *C. gayana* decreased because it is a short-lived, stoloniferous perennial grass resulting in a significant cover in the first years of a restoration application, and can therefore be regarded as a good nursing plant.

5.4.3 Density

The average densities of the oversown species of the enhanced and untreated seed in general did not differ significantly ($p = 0.58$, and Fig. 5.9). *D. eriantha*, *C. gayana* and *P. maximum* had the highest densities in both the enhanced and untreated seeded sub-plots. The average density of *D. eriantha* and *C. ciliaris* (untreated) increased over the period of four years. The density of *C. gayana*, *P. maximum* and *A. pubescens* decreased over the study period. Note the high frequency of *C. gayana* in the second year of the study period and its absence in the third year, typical of this short-lived perennial, corresponding with

Dannhauser's (1987b) statement that *C. gayana* does not have a long life span when subjected to grazing, and usually disappears from a grazed sward between the third and fifth year after establishment. *C. gayana* disappeared after four years because it is a weak perennial tufted grass that grows for two to five seasons (Van Oudtshoorn, 1999). *P. maximum* followed a similar pattern to that of *C. gayana*.

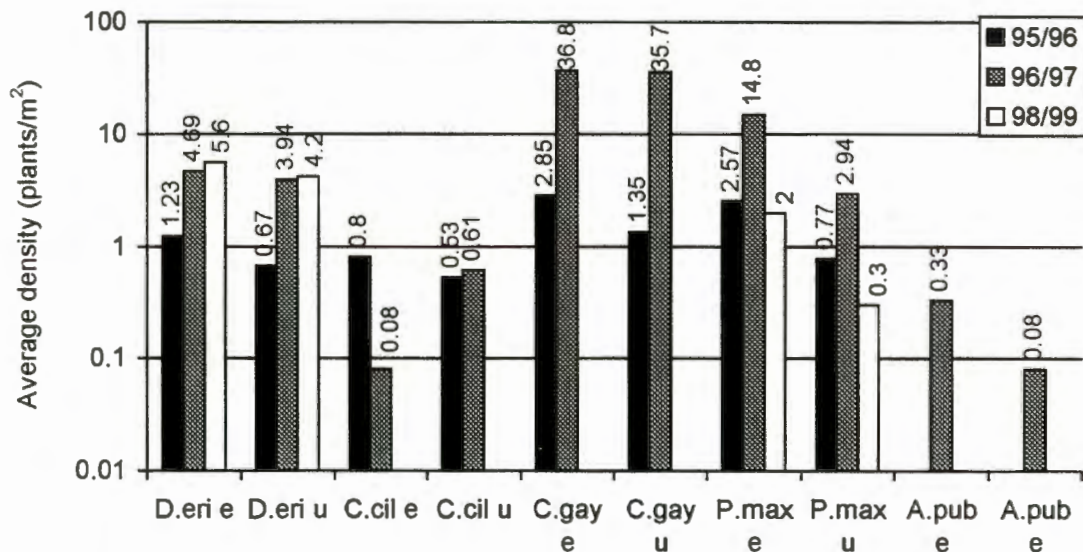


Figure 5.9: The average density of sown-in grass species (originating from enhanced (e) and untreated (u) seed) over a four year period. Soil was ripped to a depth of 200 mm before sowing.

Where *A. pubescens* (enhanced seed) (Figure 5.9, 0.1) was sown with untreated seed of either *D. eriantha* and/or *P. maximum*, the density of the *A. pubescens* plants decreased probably due to competition with the greater number of seedlings of *D. eriantha* or *P. maximum* from untreated seed.

5.4.4 Growth stages

The number of individuals in the different growth stage categories (seedling (s), vegetative (v) and reproductive(r)) of the enhanced and untreated seed did not differ significantly in the growing season of 1996-1997 ($p = 0.23$, Fig. 5.11-

5.12). *C. gayana* (seedling: 30, vegetative: 6 and reproductive: 8 for enhanced seed, Fig. 5.11; and seedling: 91, vegetative: 9 and reproductive: 7 for untreated seed, Fig. 5.12) and *D. eriantha* are the only species which were represented in the seedling, vegetative as well as reproductive stages. As mentioned earlier, *C. gayana* have a large number of seedlings because of its stoloniferous growth form and each daughter plant (ramet) was noted as a separate plant.



Figure 5.10: The study area one year after the restoration application (1996). In 1999, no *Tagetes minuta* plants (A) remained in the study area. A *Digitaria eriantha* (B) tuft occurs between the persons.

P. maximum is well represented in the vegetative and reproductive stage (vegetative: 6 and reproductive: 5, enhanced; Fig. 5.11 and vegetative: 3 and reproductive: 2, untreated, Fig. 5.12), whereas *C. ciliaris* is not represented in the seedling or reproductive stages.

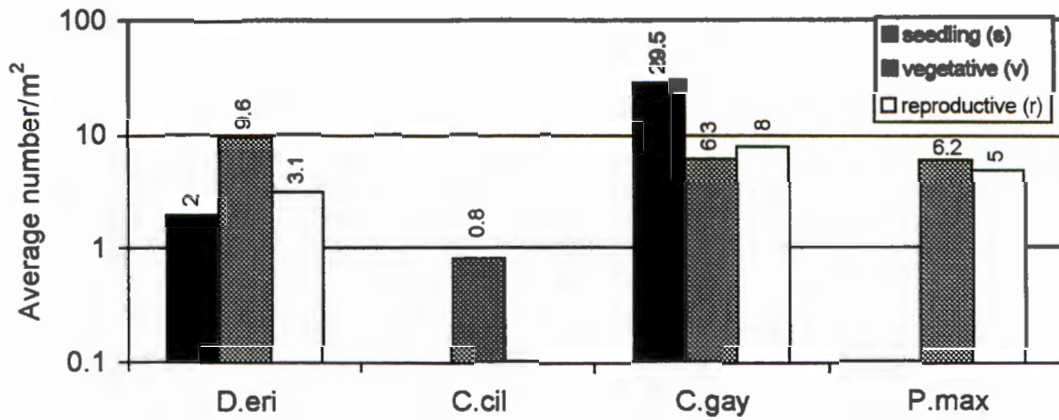


Figure 5.11: The average numbers of plants representing the seedling, vegetative and reproductive growth stages of the enhanced grass seed oversown at Tweefontein.

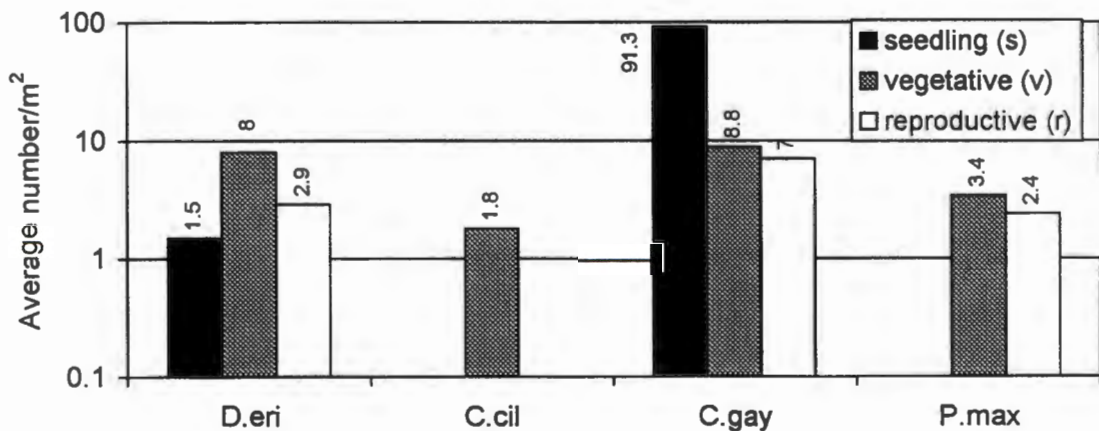


Figure 5.12: The average numbers of plants representing the seedling, vegetative and reproductive growth stages of the untreated grass seed oversown at Tweefontein.

Only enhanced seed of *A. pubescens* was oversown and no comparison between the growth stages of enhanced and untreated seed for *A. pubescens* was performed, even though the *A. pubescens* from enhanced seed were represented in all three growth stages.

5.4.5 Soil seed bank analysis

A total of 232 seedlings of 27 species germinated from the soil samples during the investigation period (1998/1999). The total seedling density varied considerably (1 – 92 seedlings/m²). The soil seed bank was dominated by the perennial grass, *Eragrostis curvula*. Of the oversown species only *D. eriantha* and *P. maximum* were represented in the soil seed bank. This implies that seed from these species could have added plants to the restoration trial. The composition of the soil seed bank included 41 % grasses (11% annuals and 30% perennials), 4% geophytes and 19% forbs (Fig. 5.13).

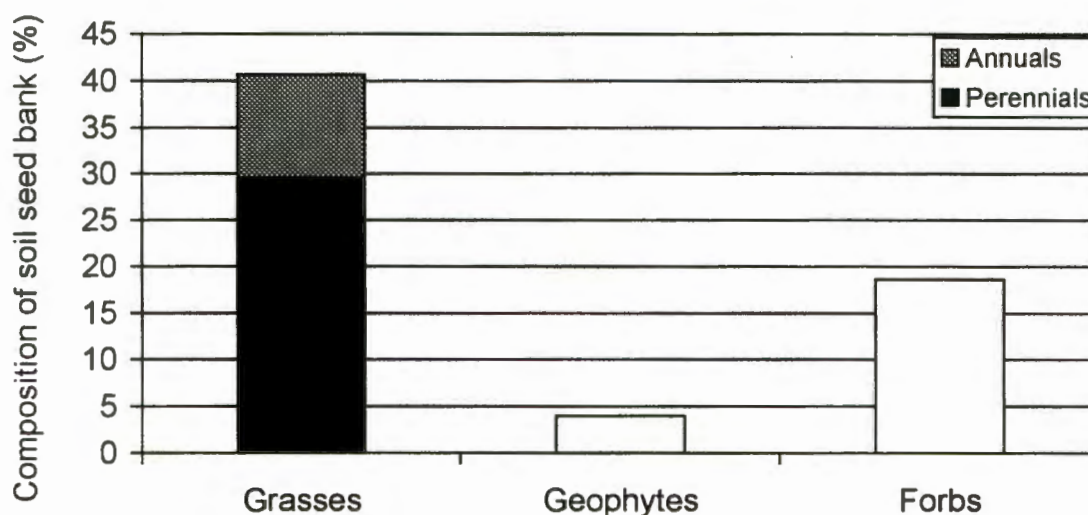


Figure 5.13: The composition of the soil seed bank at Tweefontein (growing season of 1998/1999).

5.4.6 Differences between control plots and the oversowing treatments

Two control plots, one which was just cultivated with no oversowing, and one which was in the natural pasture outside the enclosure and still grazed, were compared to treatments oversown with enhanced and untreated seed (Table 5.4). The frequency of *C. plurinodis* was reduced from 46% to 5% on the inside control (where the rip plough treatment was applied) after the first year (1996/1997) following treatment. The frequency of *C. plurinodis* in the control outside the study area, however, was 28% the first year after the restoration treatment. A further reduction in the frequency of *C. plurinodis* occurred in the

treatment. A further reduction in the frequency of *C. plurinodis* occurred in the treatments where the enhanced and the untreated seeds were used (4% and 3%, respectively, Tab. 5.3). The rip plough cultivation treatment, however, stimulated the germination and establishment of perennial grass species such as *S. sphacelata* (common bristle grass; 27 to 37%), *E. curvula* (weeping love grass; 11 to 19%) and *T. triandra* (red grass; 1 to 10%), in both the treated and control plots. It must be noted that none of these species were part of the seed mixture that was oversown.

Table 5.3. Average frequency (%) of all the grass species on the restored and control plots at Tweefontein for the period 1995 - 1999. (Species of less than 1% frequency are not shown). The oversown species are presented in bold

Species	Sub-plots with enhanced seed			Sub-plots with untreated seed			Control inside enclosure		Control outside enclosure
	95/96	96/97	98/99	95/96	96/97	98/99	95/96	96/97	96/97
<i>Antheophora pubescens</i>	4	2	2	2	5	4	0	0	0
<i>Aristida congesta</i>	2	2	0	3	2	0	6	2	3
<i>Brachiaria eruciformis</i>	1	0	0	2	0	0	0	0	0
<i>Cenchrus ciliaris</i>	13	2	1	19	4	7	0	1	0
<i>Chloris gayana</i>	31	30	0	50	64	2	0	0	0
<i>Cymbopogon plurinodis</i>	9	4	4	9	3	4	46	5	28
<i>Cynodon dactylon</i>	10	11	10	4	3	2	0	10	2
<i>Digitaria eriantha</i>	13	24	40	16	25	33	0	0	0
<i>Elionurus muticus</i>	0	1	2	0	0	1	14	2	5
<i>Eragrostis cloromelas</i>	2	1	0	2	1	0	0	2	0
<i>Eragrostis curvula</i>	4	8	8	5	7	8	0	19	11
<i>Eragrostis lehmanniana</i>	2	0	0	2	0	0	0	0	0
<i>Eragrostis racemosa</i>	3	3	4	0	2	3	6	1	9
<i>Melinis repens</i>	7	0	2	7	1	0	11	0	3
<i>Panicum dregeanum</i>	0	1	0	0	0	0	0	0	0
<i>Panicum maximum</i>	18	22	12	19	18	9	0	5	3
<i>Setaria nigrirostris</i>	1	0	0	2	0	1	0	0	0
<i>Setaria sphacelata</i>	7	18	17	7	19	24	5	37	27
<i>Themeda triandra</i>	2	1	0	3	1	1	7	10	1

An increase in frequency of grass species not present in the oversown seed mixtures proved that species richness increases when the soil is cultivated. Seeds of these grasses must have been in soil seed bank (5.4.5 & Fig. 5.13). When comparing the control plots inside and outside the enclosure 91996/1997), there are more climax grass species, such as *E. chloromelas* (2) and *C. ciliaris* (1) in the ungrazed control plot compared to the grazed plot. The type of grass species that occurred (Tab. 5.3) did not differ between the sub-plots oversown with enhanced and untreated seed. The reason would be that the species that naturally established (i.e. where not oversown) in the sub-plots oversown with enhanced seed also occurred in the sub-plots oversown with untreated seed, except for three species (*P. dregeanum*, *E. lehmanianna* and *B. eruciformis*). The most abundant species were *D. eriantha*, *S. sphacelata*, *P. maximum* and *C. gayana* (Tab. 5.4), with *Cynodon dactylon* (couch grass) and *E. curvula* also showing high frequencies. There is a great difference between the frequencies from one year to the next. The time of survey as well as the number of seedlings determined the fluctuation in frequencies between the years, e.g. there are fewer seedlings in the field in March, lowering the overall frequency.

The densities of species of the plots oversown with enhanced and untreated seed were also compared (Tab. 5.4).

The amount of quadrats (only three surveys per sub-plot) used for the density measurements were not sufficient to significantly support the frequency results. Similarities between the density and frequency data of the oversown species did, however, exist. Both the frequency and density of *D. eriantha* increased in the sub-plots oversown with enhanced seed as well as in the sub-plots oversown with untreated seed (Tab. 5.3 and 5.4). The density and frequency of *P. maximum*, *A. pubescens* and *C. gayana* decreased in the sub-plots oversown with enhanced seed and those oversown with untreated seed. The density and frequency of *C. ciliaris* decreased in the sub-plots oversown with enhanced seed. In the sub-plots oversown with untreated seed, the frequency of *C. ciliaris* increased, but the density decreased (Tab. 5.3 and 5.4). Density measurements can support frequency data if the density data stems from a sufficient number of quadrats. These similarities in the density and frequency measurements support either the increase or decrease of a particular grass species in that area and grass community.

Table 5.4. The average density (plants/m²) of all the grass species at Tweefontein inclusive of the plots using enhanced and untreated seed for the period 1995-1999. (Species with an average density of less than one plant/m² are not tabulated, unless it is an oversown species or *Cymbopogon plurinodis*)

Species	Enhanced (plants/m ²)			Untreated (plants/m ²)			Control inside			Control outside	
	95/96	96/97	98/99	95/96	96/97	98/99	95/96	96/97	98/99	96/97	98/99
<i>Antheophora pubescens</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Aristida congesta</i>	0	0	0	0	0	1	0	0	2	0	0
<i>Cenchrus ciliaris</i>	1	0	0	1	1	0	0	0	0	0	0
<i>Chloris gayana</i>	3	37	0	1	36	0	0	0	0	0	0
<i>Cymbopogon plurinodis</i>	0	0	1	0	1	1	0	2	0	7	9
<i>Cynodon dactylon</i>	0	3	12	0	3	2	1	0	0	0	0
<i>Digitaria eriantha</i>	1	5	6	1	4	4	0	0	0	0	0
<i>Eragrostis chloromelas</i>	0	0	2	0	0	1	0	1	1	0	1
<i>Eragrostis curvula</i>	0	2	1	0	1	1	0	2	1	4	0
<i>Eragrostis racemosa</i>	0	1	1	0	0	1	0	1	1	5	0
<i>Panicum maximum</i>	3	15	2	1	3	0	0	0	0	0	0
<i>Panicum stapfianum</i>	0	0	0	0	0	0	0	0	2	0	0
<i>Setaria sphacelata</i>	0	6	25	0	7	20	0	9	31	11	100
<i>Themeda triandra</i>	0	0	0	0	0	0	0	1	2	0	0

The species not oversown occurred in all the sub-plots, which means that their occurrence in the sub-plots are even. The density of *S. sphacelata* was high in all the plots inside the enclosure (20, 25, 30 plants/m²), but not as high as in the control outside the enclosure. Species having a stoloniferous nature, as well as *S. sphacelata*, showed a higher density, for example, *C. dactylon* and *C. gayana*. *Eragrostis racemosa* and *C. plurinodis* (unpalatable species) had higher densities in the grazed control plot.

5.4.7 Vegetation change over time

The change in vegetation composition over time can be expressed by trajectories on a gradient using ordination analysis techniques. All the sample plots,

represented by the different sub-plots with different seed mixture treatments, were ordinated using the DCA ordination procedure. The ordination graph displays the distribution of the sub-plots, representing the change of oversown grass species over four years (1996-1999), along the first and second ordination axes (Fig. 5.14). A restorative or succession gradient is described by the first axis. The newly restored sub-plots (1996) occur to the right of the graph, dominated by *C. gayana* (group A, sub-plots 33 and 39) and change to the *D. eriantha* (1999, group D, sub-plots 61, 58, 52) dominated sub-plots on the left. The second axis has a similar pattern with sub-plots dominated by *C. ciliaris* (1996, group B, sub-plots 19, 24, 25) changing to a *D. eriantha* dominated vegetation (group D) in 1999. Group C (Fig 5.14) can be regarded as a "transition" type of vegetation which is mainly characterized by *S. sphacelata*, *P. maximum* and *A. pubescens*. One of the main changes in all the sub-plots was the drastic reduction of the unpalatable grass, *C. plurinodis*, which is an important objective in the restoration of rangelands.

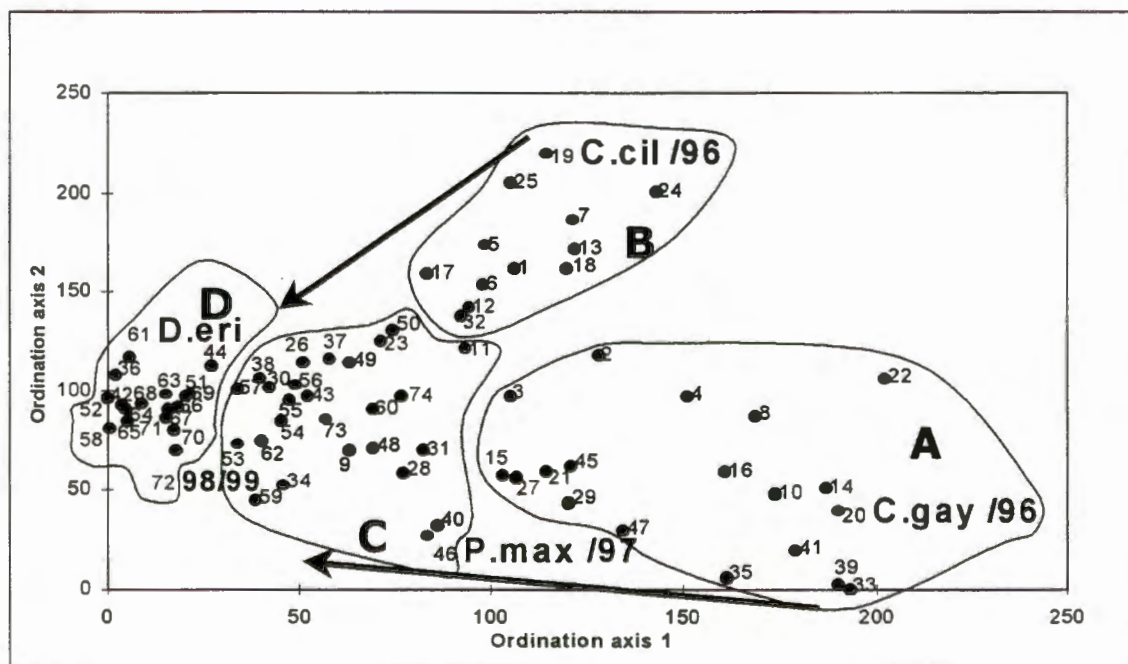


Figure 5.14: A DCA ordination showing the trajectories of the change in species composition over time (1996-1999) from a *C. gayana* (A) to a *Digitaria eriantha* (D) dominated vegetation (axis 1) and a *Cenchrus ciliaris* (B) to a *Digitaria eriantha* (D) composition (axis 2).

5.4.8 Species richness

The richness of the species increased in all the restored sub-plots over the four-year period, whether oversown with enhanced (31 species) or untreated seed (29 species). In the control sites, the species richness was much lower, namely 17 species in the grazed plot and 14 species in the control plot inside the enclosure. A total of eight different grass species other than the oversown species occurred in the study areas oversown with seed, contributing to the high species richness.

5.5 Discussion and conclusions

The number of seeds that germinated in the laboratory is much higher than the number of seedlings that would actually survive under natural conditions in the field. The untreated seed had higher germination rates in the laboratory, while the enhanced seed had greater seedling survival in the field, except for *C. gayana*, which had a lower seedling survival in the field. The total number of enhanced seed germinating in the laboratory is less, suggesting that another process is taking place, such as damage to the embryo through the chemicals used. In the field these chemicals would be leached out. This suggests that the use of enhanced seed for restoration purposes have definite advantages due to its alleviation of harsh micro-environmental conditions.

Generally, seedlings surviving from the enhanced seed had a higher survival frequency in the field trials. Pretorius⁹ (1999, February, personal communication) is of the opinion that annual and semi-perennial grasses germinating from enhanced seed have a germination advantage of two days due over the enhanced pH regime in the rhizosphere. This germination advantage is not of particular importance to perennial species, since the species germinating from untreated seed overcome the two-day germination advantage within their first year.

D. eriantha and *C. gayana* are known to have a higher germination percentage in the second year after sowing (Fair, 1986; Dannhauser, 1987b; Jordaan¹⁰, 1999, February., personal communication) and these grasses are also partly

⁹ ☒ Pretorius, H., Posbus 5311, Kokspark, 2523, ☎ 083 792 1910.

¹⁰ ☒ Jordaan, D., Dept. of Agriculture: Conservation and Environment, Louis le Grange Building, c/o Wolmarans and Van Riebeeckstr., Potchefstroom, 2520, ☎ (018) 297 5330.

stoloniferous (Gibbs Russell *et al.*, 1990; Van Oudtshoorn, 1999) in nature, making them rapid spreading species that established easily. *D. eriantha* has the second highest frequency. The average rainfall for November 1995 and February 1996 was approximately 95-105 mm, and 164 mm for December 1998 and 121 mm for January 1999 (Fig. 5.2). In other words, the summer season of 1995/1996 had rainfall of between 95 and 105 mm/month, whereas the season 1998/1999 had a higher incidence of rainfall of 164 to 121 mm/month. The increase in density of *D. eriantha* did have a time lag related to this latter incidence of rain in the sense that the increase in density was measurable in the vegetation one or two months after the rainfall event. The other oversown species did not have this same time lag associated with rainfall. This study supports the observation of many other studies stating that precipitation is the main driving force in the species composition of semi-arid areas (Peel *et al.*, 1991; Snyman & Fouche, 1991).

P. maximum often occurs together with *D. eriantha* as in this study (Scholes & Walker, 1993) due to similar habitat preferences. Warm-season grasses like *P. maximum* are not capable of spreading rapidly by vegetative means (Tainton, 1981) and are thus less competitive than the former two species (Dannhauser, 1987c; Van Wyk¹¹, 1999, February, personal communication). These species need very specific environmental conditions for good establishment and would therefore not always be a good option for use in grass mixtures for restoration purposes. The high germination rate of *A. pubescens* can be attributed to the high number of embryos per seed found in this species (ISTA, 1999⁸, see p. 71). The grass *C. ciliaris* which was used in the seed mixture during the oversowing treatment is not adapted to the high silt and clay content soils found in the study area (Dannhauser, 1987a). The potential of *C. ciliaris* for restoration purposes was not yet established. This is reflected in the low seedling survival rates in the field (Fig. 5.6 & 5.7). This grass did not establish well under natural conditions, which proved that, although the seeds were viable, the species must be adapted to the soil and climate before it can be used in the field. From the results it is evident that, given the local environmental conditions, the grasses, *C. gayana* and *D. eriantha* (enhanced) are best suited (Fair, 1986) for restoration practices in similar environments (see Section 5.3.1).

The density data supported the trends of the frequency data.

¹¹ ✉ Van Wyk, F., Ekorehab, Interal Box 21, PU for CHE, Potchefstroom, 2520, ☎ (018) 297 7320.

In this study, the presence of all three plant growth stages (seedling, vegetative and reproductive) of a species is regarded as a healthy, sustainable population. This was found for *C. gayana* and *D. eriantha*, which therefore form self-sustainable populations when sound management practices are applied (Tainton, 1999). *C. ciliaris* and *A. pubescens* have not formed self-sustainable populations in the study area. It seems, therefore, that these two species are less adapted to the quartzites and shales that give rise to a soil of sandy-clay-loam texture (Van Oudtshoorn, 1999) with a clay content of 25% and a $\text{pH}_{\text{H}_2\text{O}}$ of between 6 and 7. The average short-term rainfall is 596 mm/yr. The month and timing of vegetation surveys in relation to the amount and availability of moisture influence the growth stage data to a great extent, because seedling germination and even the subsequent survival of the seedlings is dependant upon rainfall (Barbour *et al.*, 1987). Therefore all the surveys were conducted during the second part of the main rain and growing season, i.e. February/March of each year. This practice is advised for future studies of similar nature.

The soil seed bank at the time of the soil seed bank survey, had the extent of a single season pilot study and points in the direction of possible dominant species. This preliminary soil seed bank study also gave an indication of the amount of time needed for oversown species to occur in the soil seed bank, e.g. three years before *D. eriantha* and *P. maximum* appeared in the soil seed bank. The species richness of the soil seedbank increased during the study period (Tilman *et al.*, 1996).

The rip plough cultivation method had a negative effect on the re-establishment of *C. plurinodis*. This complied with the aim of this study; i.e. to remove or decrease the abundance of the unpalatable large tufted *C. plurinodis* grasses dominating the degraded sward. This cultivation treatment on the other hand stimulated the germination and establishment of species such as *S. sphacelata*; *E. curvula* and *T. triandra*. It must be noted that not one of these species was part of the seed mixture that was oversown. When comparing the control plots inside and outside the enclosure, there is more climax grass species in the ungrazed control plot, which correlated with other grazing studies. Kellner (1995), Martens & Zacharias (1996) and Morris & Tainton (1996) obtained similar results where vegetation dynamics studies of grazed and ungrazed plots were investigated over similar time periods.

The number of species (Table 5.4) does not differ between sub-plots oversown with the enhanced and untreated seed. Grass species that regenerated during succession were evenly spread over all the sub-plots, most probably due to the even rip plough treatment and broadcasting of seed over the total study area. Grass seed of this size are all anemochorous defined as dispersed by wind or having seeds so dispersed (Lawrence, 1989, Lyaruu, 1999). Spreading further than approximately 2m from the mother plant is minimal (Bakker, 2000) due to the weight of the seeds. In this distance heavier seeds fall close to the mother plant, while lighter seeds disperse further away (Strykstra *et al.*, 1998).

The dynamics of the specific grassland seed banks need a more focused analysis over a longer time before concrete conclusions can be drawn. Seasonal (spring, summer, autumn and winter) analyses over the full period of the study (e.g. 5 years) are recommended (Bakker, 2000). Dominant grass species have been identified as well as species from the mixtures oversown into the sub-plots.

When the data was analysed using DCA ordination techniques (Hill, 1979) to determine vegetation change over time by trajectories, it was clear that a distinct restorative or succession gradient exists on the first and second axes. All the sub-plots were dominated by *D. eriantha* in 1998/1999. The conclusion is that *D. eriantha* is an ideal species to use during restoration practices for this given area. *P. maximum* is dominant in the transitional group and could also be considered for restoration in the short term in this specific area.

A mixture of *D. eriantha*, *C. gayana* and *P. maximum* is advised for this specific area, with *A. pubescens* being an additional potential candidate. Where enhanced seed of *A. pubescens* was oversown in the sub-plot together with untreated seed of other species; there was an increase in the frequency of the enhanced seed (Fig. 5.8), once again suggesting that enhancement provides the seed with benefits not available to untreated seed.

Although the dynamics of the oversown grass species are largely environmentally driven, adaptability to specific habitats determines the suitability of a grass species to a specific habitat. Disturbance and oversowing stimulate certain species to increase in frequency and are detrimental to other species, which in this case is beneficial because the dominant species, *C. plurinodis* was eradicated and replaced with a palatable, perennial sustainable sward (Kellner, 1995).

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Chapter 6. An assessment of rehabilitation treatments in degraded Mixed Grassland vegetation of the North West Province, South Africa

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(This chapter is prepared for submission to the *Journal of Arid Environment*². The photographs, title numeration and cross-references appropriate to the dissertation will not appear in the manuscript submitted to the journal)

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6.1 Abstract

Treated (enhanced - e) and untreated (u) caryopses of *Chloris gayana* (Rhodes grass), *Cenchrus ciliaris* (foxtail buffalo grass), *Panicum maximum* (guinea grass) and *Anthephora pubescens* (wool grass) were oversown in different mixtures into part of an eroded, semi-arid pasture as a restoration experiment. The relationship between the grass composition and the soil seed bank was also examined. Statistical analyses included descriptive statistics, significant differences and multivariate data analysis. The most suitable grass mixture for this eroded soil type (characterised by a sandy-clay-loam texture, a clay percentage of 29% and a pH value of 5) was one containing *C. ciliaris* (u) and *A. pubescens* (u). To quantitatively determine species abundance over the long-term, frequency and density measurements have been used. The frequencies of *C. gayana* (e), *C. ciliaris* (e) and *P. maximum* (u), were stable during the study period. The frequency of *A. pubescens* (e) increased and *C. gayana* (u), *C. ciliaris* (u), *A. pubescens* (u) and *P. maximum* (e) decreased. Density increased for both seed types of *A. pubescens* and *C. ciliaris* (u). The densities of the other oversown species were stable. The soil seed bank analysis showed that 317 seedlings of 37 species germinated from the soil samples, which reflected tendencies in current literature. A restorative or succession gradient exists on the second axis of the ordination, with the vegetation composition changing from pioneer dominated vegetation in 1996 to *C. ciliaris* or *A. pubescens* dominated pasture in 1999. The grass species richness increased from four to 12 species in the 1ha study area. It is concluded that the rate of succession increased where seeds of perennial climax grasses were oversown after rip ploughing.

Keywords: commercial farm, sustainability, enhanced and untreated seed, restoration, natural pasture, mixed grassland

6.2 Introduction

One school of thought describes desertification and degradation as the result of overgrazing and other human impacts on a potentially stable ecosystem (Norton & Sandor, 1997; Bosch & Kellner, 1991). According to this school, once these stable ecosystems are disturbed, restoration practices could return the ecosystem to a stable condition. Another school of thought, however, states that stable equilibriums are not achievable in many pastoral ecosystems, even though long-term persistence

is. They also suggest that interventions aimed at achieving stability are likely to be irrelevant or disruptive, and that successful interventions will be designed to accommodate system dynamic variation rather than trying to maintain equilibrium conditions (Ward *et al.*, 1998).

Commercial land tenure systems experience degradation due to bush encroachment, fields composed of annual grasses and the increase of bare, denuded patches by soil erosion. For example, a pasture dominated by *Themeda triandra* (a species of high ecological status) can degrade because of overgrazing to a field dominated by *Aristida congesta* (a species of poor ecological status, Janse van Rensburg & Bosch, 1990). Much vegetation of semi-arid pastures worldwide are unstable, with marked year-to-year fluctuation in species composition (Allen *et al.*, 1995; Huffaker & Cooper, 1995; Dzwonko & Loster, 1998; O'Connor & Everson, 1998; Fair *et al.*, 1999). The fluctuation in species composition is closely linked to the rainfall patterns of the area and therefore attempts towards restoration of such degraded pastures should take the many factors mentioned in Chapter 1, such as geology, soil characteristics, community involvement, into account (Harris *et al.*, 1996; Kellner, 1995). With the correct extension services and restoration practices, degradation can be combated and sustainable pastoralism encouraged (Milton & Dean, 1995; Bertiller, 1996; Cairns & Heckman, 1996; Haro *et al.*, 1996; Dobson *et al.*, 1997; Düvel, 1999; Guerrero-Campo *et al.*, 1999). Poorer veld condition may lead to accelerated erosion.

Several definitions for sustainability exist. The most popular is that of an agroecosystem that maintains the resource base on which it depends, relies on a minimum of artificial inputs from outside the farm system, manages pests and diseases through internal regulating mechanisms, and is able to recover from the disturbance caused by grazing for example. The parameters for the description of sustainability are, however, not yet clearly defined or described (Gliesman, 1998). This study used the prolonged presence of the oversown species and plant growth stages over four years as a parameter of sustainability.

Special technologies (Call & Roundy, 1991; Kellner, 1995) are necessary to establish vegetation on eroded soil, e.g., using enhanced seed (see Section 2.3) or rip plough cultivation (see Section 2.2 in Chapter 2; Pretorius, 1990; Van der Merwe, 1997). Seed enhancement is a post-harvest treatment that improves seed germination or facilitates seed and/or nutrient delivery (Taylor *et al.*, 1998). In South Africa, the benefit of the technology of seed enhancement has not yet been established

scientifically. The aims of this study is to evaluate the influence of an oversowing and rip plough cultivation restoration treatment with enhanced (treated) and untreated seed on the vegetation condition of the pasture and evaluating the increase of species richness of the rangeland. Similar studies on oversowing were conducted by Sheley *et al.* (1999), but they did not compare enhanced with untreated seed. Quantitative vegetation sampling methods, such as species frequency and density, were used to determine changes in species abundance over time (period of four years 1997-2000). Experimental areas where a restoration treatment, including oversowing, were used, were compared to resident grass populations in the areas (Meyer & Schmid, 1999; Morgan, 1998; Wilman *et al.*, 1999).

6.3 Materials and methods

6.3.1 Study area

A degraded area on a commercially managed farm, Totiuskraal (26°53'S, 27°13'E) was chosen to address the dominance of *C. plurinodis*. The farm is situated 50 km south east of Potchefstroom in the North West Province (South Africa), (Fig. 6.1). The study area, a footslope, has an altitude of 1364 m (Land Type Survey Staff, 1984a).

As part of the Grassland Biome (Rutherford & Westfall, 1994), the vegetation on the farm is classified as Mixed Grassland by Acocks (1988). The area experienced patches of sheet erosion (Matthee & Van Schalkwyk, 1990) prior to the restoration application. It was characterised by annual, pioneer grass species such as *Aristida congesta* (tassel three-awn grass), *Aristida canescens* (pale three-awn grass), *Tragus berterianus* (carrot-seed grass) and *Chloris virgata* (feather-top chloris) (Van Oudtshoorn 1999). All these grass species are species of low ecological status in respect of their forage quality (Van Oudtshoorn, 1999). The long-term rainfall for the area, in a typical summer growing season, from October to April, is 617 mm/yr. (Fig. 6.2). The first rainfall pulse in 1996 (the year of oversowing and seedling establishment) was 10 days prior to the oversowing period in February 1996. A subsequent peak in April 1996 ensured the survival of seedlings. Marked rainfall peaks also occurred in October and December 1995, and January and March of 1997. Annual rainfall totals showed marked fluctuation.

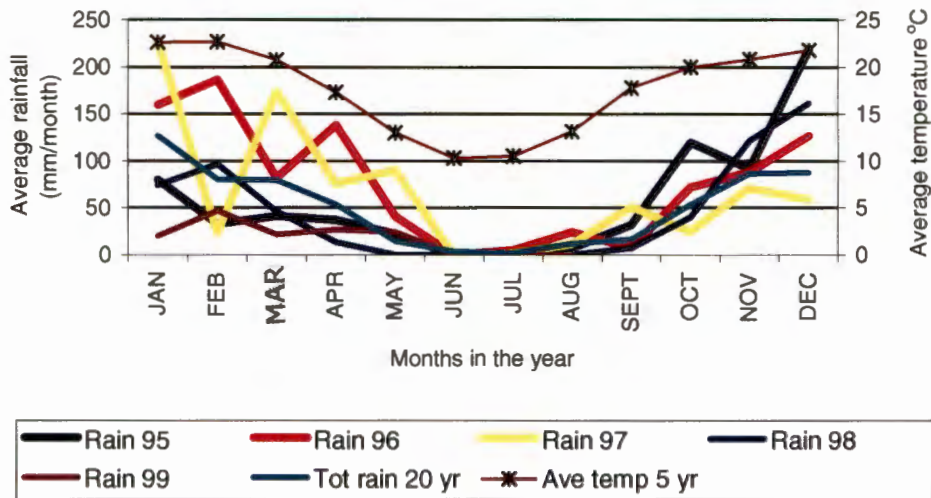


Figure 6.2: The average long-term (20 yrs.) and short-term (1995-1999) rainfall and average temperature (°C) for the Totiuskraal study area.

The remaining months tend to have a low average rainfall. High rainfall in these months is not generally useful in terms of pastures, as it is unpredictable and isolated.

During the study period, 1995-1999 an average precipitation of 773 mm/yr. was recorded (AgroMet, Potchefstroom⁴), which is more than the average long-term rainfall. The minimum temperature for the period 1995 to 1999 was -8 °C. The maximum temperature for the period 1995 to 1999 was 36 °C.

The soil originates from a diabase of the Transvaal age (Keyser, 1997) and the land type is therefore classified as a Bc25c land type with a Shortlands glendale soil form (Land Type Survey Staff, 1984a). According to the texture, the soil is classified as sandy-clay-loam (49% sand, 35% silt and 16% clay). The average pH_{H2O} of the soil is 5 (Department of Conservation and Environment: Geology Section⁵). The concave

⁴ AgroMet Potchefstroom, Institute for Soil, Climate and Water, P/b x1251, Potchefstroom, 2520.

⁵ Department of Conservation and Environment: Geology Section, P/bag X 804, Potchefstroom, 2520.

mid slope of 3° faces west and has an orthic soil (largely eroded) overlying a red structured B-horizon (Land Type Survey Staff, 1984a).



Figure 6.3: An example of rip ploughing in the study area at Totiuskraal. Seed of perennial grasses were oversown in the furrows.

6.3.2 Restoration treatment

The total study area was fenced off and four plots were rip ploughed to a depth of 70 mm with the plough-rows 200 mm apart. Four plots were randomly placed in the study area (Fig. 6.3).

Seeds of climax grass species (Table 6.1), all native to the area, except *C. gayana* which is naturalised from India), were oversown by hand into the furrows and slightly covered with soil. The total area treated was approximately 1ha. The four plots were subdivided into a total of 10 sub-plots. Each sub-plot was 50 x 10 m in area. Five of these sub-plots were oversown with enhanced seed and five were oversown with untreated seed (Table 6.1). No grazing occurred during the study period (1995 - 1999). Grazing did, however, occur in the control area outside the enclosed restored area. The size of the control plot was such that five repetitions of density surveys and 100 wheelpoint surveys could be done. The seed mixture used in the oversowing treatment included three perennial climax grasses, *C. ciliaris*, *P. maximum* and *A. pubescens*, and one short-lived perennial, *C. gayana*, (Table 6.1). Both enhanced and

untreated seeds were used in the experimental plots, and the amount of seed per gram oversown varied according to seed size and weight (Table 6.1). Due to little variation between the results of the different applications of enhanced and untreated seed, the combined results were used to compare the species composition.

Table 6.1: The average weight (in kilograms/hectare) of seed oversown in different mixtures and the average number of seed per gram (in brackets) at the Totiuskraal study area, North West Province, South Africa. 50% more by mass of enhanced seed than untreated seed were used

Species	Treatment	Sub-plot 1	Sub-plot 2	Sub-plot 3	Sub-plot 4	Sub-plot 5
<i>Chloris gayana</i> (C.gay)	Enhanced	0.6 (646)	0.6	0.6		0.4
<i>Cenchrus ciliaris</i> (C.cil)	Enhanced	0.4 (2655)			0.3	0.3
<i>Panicum maximum</i> (P.max)	Enhanced		0.4 (546)		0.3	0.3
<i>Anthephora pubescens</i> (A.pub)	Enhanced			0.7 (28)	0.5	
		Sub-plot 6	Sub-plot 7	Sub-plot 8	Sub-plot 9	Subplot10
<i>C. gayana</i>	Untreated	0.4 (3778)	0.4	0.4		0.3
<i>C. ciliaris</i>	Untreated	0.3 (399)			0.2	0.2
<i>P. maximum</i>	Untreated		0.3 (1994)		0.2	0.2
<i>A. pubescens</i>	Untreated			0.5*	0.3	

* *A. pubescens* seed not available at the time of oversowing

The enhanced seed is heavier than the untreated seed and thus had less seed per kilogram. Therefore 50% more of the enhanced seed was oversown following recommendations of Advance Seed³.

6.3.3 Field sampling methods

Vegetation surveys were carried out in the growing season during the summer of 1996/1997, 1998/1999 and 1999/2000. The vegetation composition prior to restoration application was determined. In each sub-plot the frequency of the grass species was determined as the 100 nearest plants to the pointed tip of the wheelpoint

³ ☒ Advance Seed, P.O. Box 414, Krugersdorp, 1710, South Africa, ☎ + 27 11 762 5261 (o), 11 762 4111 (f)

apparatus (Tidmarsh & Havenga, 1955). A quadrat (1 x 1 m; Barbour *et al.*, 1987) was placed randomly in each sub-plot to determine the density of each species in the different treatments. Three replicate quadrats per sub-plot were monitored.

6.3.4 Soil seed bank analysis

Soil samples for the soil seed bank analysis was collected during the summer of 1998/1999. Three soil samples per grid were collected with a soil auger (~ 1006 cm³, Du Toit & Alard, 1995) and allowed to air dry for two weeks. The three samples of each sub-plot were combined (~ 3017 cm³) in a 300 x 200 x 80 mm (4800 cm³) seed tray. The soil samples that were taken were greater than 100 cm³ soil sample in each 1 x 1 m plot. Seed germination rate was determined by the germination of the seeds in the soil (Tsuyuzaki & Kanda, 1996). The analysis was done in a greenhouse where the temperature cycled from 28 °C during the day to 20 °C at night. The soil was kept moist (Du Toit & Alard, 1995; Schrautzer *et al.*, 1996). The species were allowed to germinate (first appearance of the radicle and the plumule according to Weinbrenn, 1946) and left until identification was possible. Where two or more of the same species germinated, all but one specimen was removed to reduce competition for light and nutrients between the seedlings. Identified species were also removed for the same reason (see Section 4.2.2). The results of the soil seed bank analysis were noted and compared to the standing grasses in the study area. A period of 150 days is sufficient for only 2% of seed to remain in the soil (O'Connor & Everson, 1998).

For the soil seed bank analysis, seedling density per 1 x 1 m x 0.02 m was calculated as follows:

Three samples of >1006 cm³ soil were combined. The three samples added up to 4800 cm³ (amount of soil fitted into 300 mm x 200 mm x 80 mm containers). That is converted to 1 x 1 m x 0.02 m, as a measurement of the seedling density per square meter in the field.

For example, 139 seedlings germinated from a seed tray. Converting the number of seedlings/cm³ to the number of seedlings/1 x 1 m x 0.02 m (20 000 cm³ is the conversion factor):

$$\frac{139 \text{ seedlings/cm}^3 \times 20\,000 \text{ cm}^3}{4800 \text{ cm}^3}$$

$$\begin{aligned} &\text{or } \frac{139 \text{ seedlings/0.048 m}^3 \times 0.02 \text{ m}^3}{0.0048 \text{ m}^3} \\ &= 579.17 \text{ seedlings/0.02 m}^3 \end{aligned}$$

$$\text{or } 579.17 \text{ seedlings/1 x 1 m x 0.02 m} \dots\dots\dots 6.1$$

6.3.5 Data analysis

The quantitative data was analyzed statistically using the ANOVA/MANOVA technique in the STATISTICA for Windows (StatSoft, Inc., 1999) computer program. The purpose was to find significant differences between the means of a variable by comparing that variable's variances. Results were considered statistically significant if $p < 0.05$, except where otherwise indicated.

Using multivariate analysis techniques e.g. DECORANA (Hill, 1979), the change of species composition over time was determined by trajectories on a gradient. DCA-ordination was used for the gradient analysis conducted in the Integrated System for Plant Dynamics (ISPD) computer package (Bosch *et al.*, 1992).

6.4 Results

6.4.1 Frequency and density of the oversown species

None of the species oversown occurred in the study area prior to restoration. The average frequencies of the oversown species developed over a period of five years as shown in Fig. 6.4. *C. ciliaris*, for example, decreased from 20% in 1996/1997 to 8% in 1999/2000. The species composition of the sub-plots oversown with enhanced and untreated seed did not differ significantly from one another with regard to frequency and density. The difference in frequency between the species oversown for the years 1996/1997, 1998/1999 and 1999/2000 was, however, significant ($p = 0.00$, Table 6.2). An asterisk in Table 6.2 shows significant differences.

A. pubescens from untreated seed had the highest frequency (36.5%), followed by *A.*

pubescens (24%) from enhanced seed and *C. ciliaris* (8%) from untreated seed. The summer season of 1998/1999 had the highest frequencies of all the years in which the study was conducted. The only oversown grass that increased over the study period is *A. pubescens*, which established from enhanced seed (Fig.6.4 & 6.5).

Table 6.2: The analysis of variances (p-value) for the Totiuskraal study area based on the Scheffe test (* indicates significant differences)

	Sub-plot	Species	Treatment	Year
Frequency	0.42	0.00*	0.11	0.03*
Density	0.42	0.02*	0.11	0.16

The density and frequency of the oversown species are similar (Fig. 6.5). *A. pubescens* from enhanced seed had the highest density (80.8 plants/m²), followed by *A. pubescens* from untreated seed (14 plants/m²) and *C. ciliaris* from untreated seed (4 plants/m²) (Fig.6.6). The density of all three of these species increased during the study period.

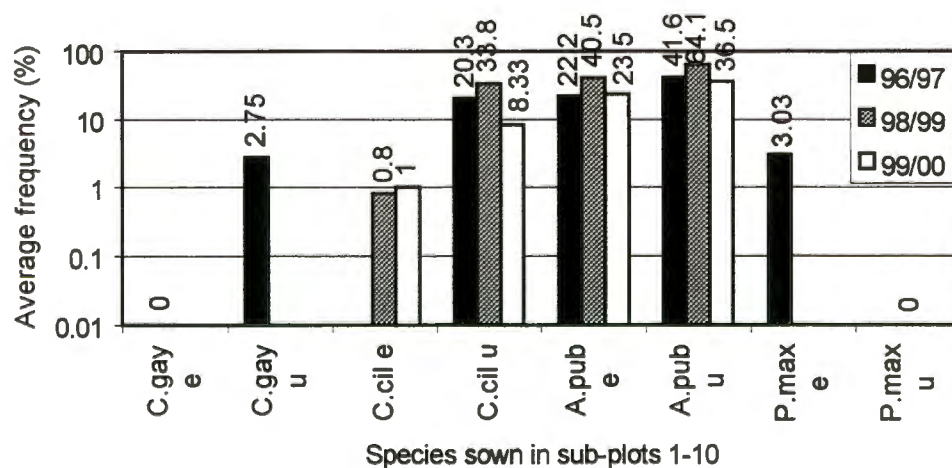


Figure 6.4: The average frequency of the oversown grass species (see Table 6.1) at Totiuskraal over a period of five years (1996-2000), using enhanced (e) and untreated (u) seed oversown in rip furrows 70 mm deep and 200 mm apart.

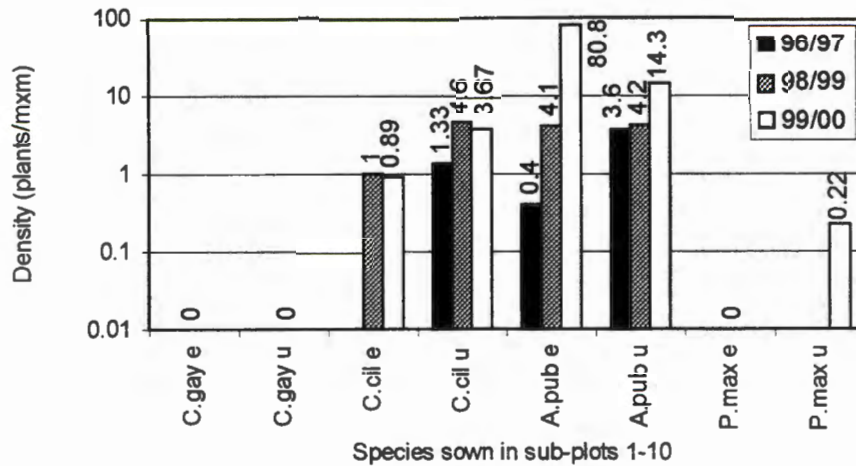


Figure 6.5: The average density of the oversown grass species (see Table 6.1) at Totiuskraal over a five year period, using enhanced (e) and untreated (u) seed oversown in rip furrows 70 mm deep and 200 mm apart.

Only *C. ciliaris* and *A. pubescens* benefited from the untreated seed. For the other oversown grass species the enhanced and untreated seed yielded the same results. Although 50% more (by weight) of the enhanced seed was oversown than the untreated seed, the enhanced seed of *C. ciliaris* did not have a higher frequency or density than the untreated seed. *A. pubescens* from enhanced seed did have a higher density than the untreated seed, but not a higher frequency.

Thus it seems that the untreated seed of especially *C. ciliaris* as well as *A. pubescens* are the best suited for oversowing in a restoration treatment in an environment of diabase geology, sandy clay loam texture, pH of 5 and an average short-term rainfall of 773 mm/yr.

6.4.2 Frequency of species not oversown

In the sub-plots oversown with enhanced seed, three species had stable populations, namely *Urochloa panicoides* (garden urochloa), *Cynodon dactylon* (bermuda grass)

and *Melinis repens* (Natal red top). *Urochloa panicoides* is a species with surface spreading roots to utilize soil surface water and therefore are able to survive where deep rooted grasses will not. *C. dactylon* has rhizomes, which regenerates the plant even when the rhizomes are fragmented. Their population, in part, stabilized because the roots are adventitious. *Melinis repens* is known to appear in areas that are disturbed by rip ploughing, for example. The other grass species in the enhanced sub-plot had different frequency tendencies. The dominant species, *Aristida canescens*, decreased over the study period. As a species adapted to the more dry, eroded environment, this species did not proliferate in the improved environment. The benefit of this decrease will be discussed in Section 6.5.



Figure 6.6: *Anthephora pubescens* increased in the degraded area (1996-1998) after the restoration treatment at the Totiuskraal study area.

Two species, *Themeda triandra* (red grass) and *Chloris gayana* (Rhodes grass) first increased and then decreased and at first the rainfall was blamed for this decrease, but the *T. triandra* in the other sub-plots (u) did not decrease even though they received the same rainfall. The most plausible explanation for *T. triandra* decrease in the enhanced sub-plot will be discussed in Section 6.5. *C. gayana* is known to decrease from the second year onward.

Table 6.3: The average frequency (%) of all the grass species at the study area of Totiuskraal for the period 1995 – 2000. (Species of less than 1% average frequency are not shown)

	Enhanced			Untreated		
	96/97	98/99	99/00	96/97	98/99	99/00
<i>Aristida canescens</i>	57.6	42.9	5.8	40.3	15.8	12.2
<i>Aristida congesta</i>	0	0	24.6			
Bare ground*	2.84	0.46	1			
<i>Cynodon dactylon</i>	1.6	2.3	1.6	4.84	14.5	7.2
<i>Eragrostis curvula</i>				0.22	0.48	1.2
<i>Heteropogon contortus</i>	1	9.74	6	2.54	8.2	12
<i>Melinis repens</i>	1.93	8.58	8.4	2.14	4	8.8
<i>Setaria sphacelata</i>	0.38	0	1			
<i>Themeda triandra</i>	1.52	5.38	1.8	0.82	6.76	7.6
<i>Tragus berteronianus</i>	19.1	7.12	35.8	13.5	2.96	26
<i>Urochloa panicoides</i>	2.5	3.18	2.8	2.02	0.2	2.8

* Prior to the restoration application (1995/1996) bare ground had a frequency value of 52%

The slight increase of *Tragus berteronianus*, *Heteropogon contortus*, *Setaria sphacelata*, and *Aristida congesta* will also be discussed in Section 6.5. *T. berteronianus* and *A. congesta* are indicators of disturbance, e.g. rip ploughing and *H. contortus* and *S. sphacelata* are perennial species adapted with larger tufts to live for longer periods.

The scenario for the not oversown species in the untreated sub-plots differs markedly from the scenario found in the enhanced sub-plots. In the untreated plots, the surface rooted *U. panicoides* is the only species with a stable population. In these untreated sub-plots, the dominant species, *A. canescens* and interestingly, *C. dactylon* decreased. Typical disturbance indicator grasses, e.g. *T. berteronianus* and *M. repens* steadily increased with numbers greater than those for the enhanced sub-plots. The other species that steadily increased (*H. contortus*, *T. triandra* and *E. curvula*) were all palatable perennial species. The reasons for their increase will also be discussed in Section 6.5. Differences between the control plots and the treated sub-plots are not discussed due to insufficient data for the control plots.

6.4.3 Soil seed bank analysis

A total of 317 seedlings of 23 species germinated from the soil samples taken for the soil seed bank analysis during the investigation period. The total seedling density varied considerably (4 - 388 seedlings/1 x 1 m 0.02 m).

None of the oversown species were represented in the soil seed bank, but four perennial grasses were present, namely *Hyparrhenia hirta* (common thatching grass), *D. eriantha*, *T. triandra* and *Brachiaria serrata* (sweet signal grass). The soil seed bank was composed of 39% grasses, of which 26% were annuals (mainly *A. congesta*) and 13% perennials, and 61% forbs (Fig. 6.7).

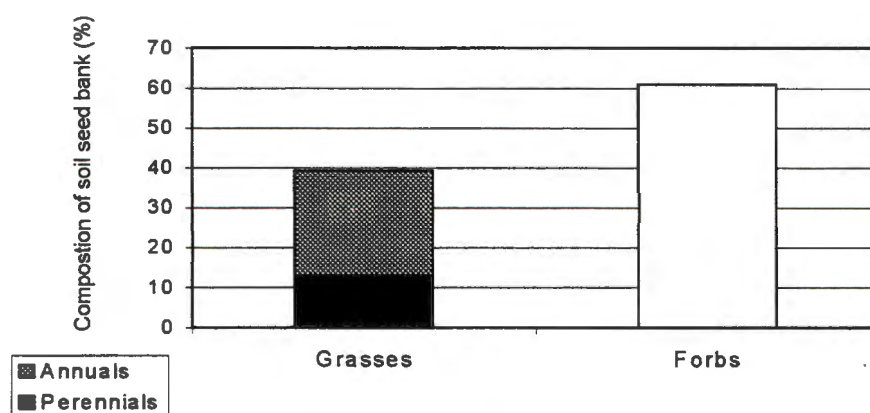


Figure 6.7: The composition of the soil seed bank at the study area of Totiuskraal for the 1998/1999 season.

Even in this degraded area, a large soil seed bank is present and restoration treatments that include soil disturbance will possibly result in the germination and establishment of species as shown in Section 6.4.2.

6.4.4 Trajectories over time

Trajectories on a gradient can be used to express the change in vegetation composition over time. This expression of vegetation change made use of ordination analysis techniques. All the different sample plots, represented by the different sub-

plots with different seed mixture treatments were ordinated using DECORANA (a DCA - ordination technique) (Hill, 1979). In the ordination graph, as shown by the scatter diagram (Fig. 6.8), the distribution of the sub-plots representing different grass mixtures are depicted along the first and second axes. The distribution of the sub-plots indicates a distinct discontinuity between the sub-plots just after the restoration practice (1996) and those of three years later (1999). The scatter diagram also illustrates two communities. A group of sub-plots (16, 20) dominated by *C. ciliaris* (group A) occurred to the right of the diagram and axis 1, while a group of sub-plots (14, 18, 19) dominated by *A. pubescens* (group B) occurred to the left of the diagram. Two distinct plant communities have developed over time, both from an *A. canescens* dominated sward, represented by sub-plots 1, 2 & 5 in 1996 (Fig. 6.8), indicating a succession gradient along axis 2 from a pioneer (annual) to a climax (perennial) dominated sward. The sub-plots (with a high occurrence of bare ground and annual grass species such as *A. canescens* and *T. berteronianus*), at the start of the trial in 1996/1997 (at the top of the diagram) change to the sub-plots of 1998/1999 at the bottom of the axis (with perennial, climax grass species such as *H. contortus*, *T. triandra*, *A. pubescens* and *C. ciliaris*). This change in species composition from pioneer to climax species can also be expressed as an increase in the overall condition of the natural rangeland (Bosch & Kellner, 1991).

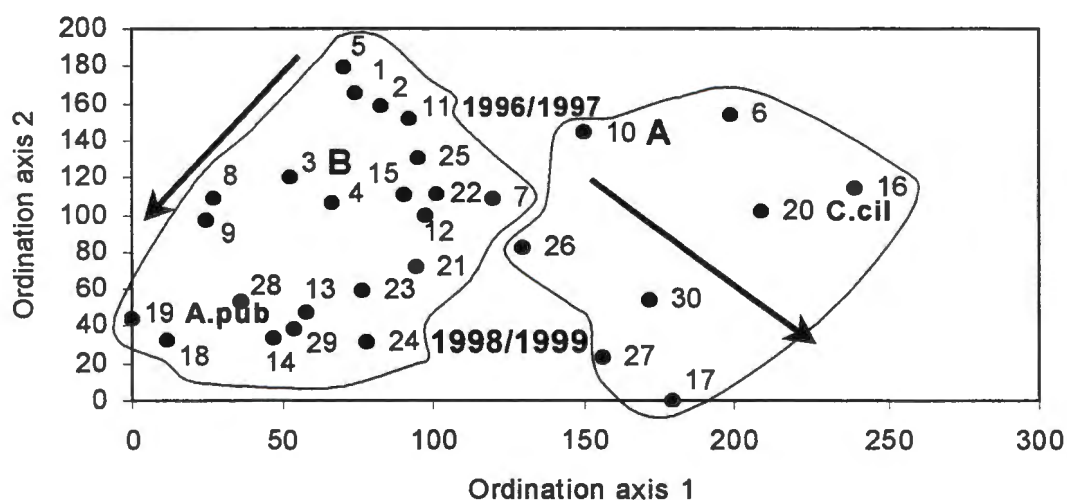


Figure 6.8: A DCA ordination showing the trajectories of the change in species composition over time (1996-2000) from an *Aristida canescens* dominated vegetation (axis 2) to either a *Cenchrus ciliaris* (group A) or an *Antheophora pubescens* dominated (axis 1, group B) vegetation.

6.4.5 Species richness

To determine the increase in species richness as a result of the restoration treatment, the frequency of the other grass species in the area was also monitored. In the sub-plots oversown with untreated seed (Table 6.3), *Urochloa panicoides* (garden urochloa), *Tragus berteronianus* (carrot-seed grass), *Heteropogon contortus* (speargrass), *Themeda triandra* (red grass), *Melinis repens* (Natal red top), *Eragrostis curvula* (weeping love grass) and *Microchloa caffra* (pincushion grass) increased during the study period of 1996 to 2000.

A. canescens (pale three-awn) and *C. dactylon* (bermuda grass) decreased during the study period. It is interesting to note that perennial grasses mostly increased in the sub-plots oversown with untreated seed, whereas most of the annual grasses decreased.

The study area was dominated by bare ground (52%) and three grass species, namely *A. canescens* (20%), *A. congesta* (15%) and *T. berteronianus* (12%) before restoration application. Five years later the grass species richness increased by 12 grass species, including both annual and perennial grass species (Table 6.3). A restoration treatment that includes cultivation and oversowing therefore increases species richness of especially perennial grasses after a period of three years. The benefit of soil disturbance for not only oversown species but for the total species composition is evident and supported by several studies (Adams, 1996; Edwards & Crawley, 1999a).

This will also result in an overall improvement of the condition of the veld culminating in a higher production and grazing capacity.

6.5 Discussion and conclusion

At this specific study area the untreated seed of *A. pubescens* and *C. ciliaris* used in the oversowing treatment showed the best results with regard to an increase in frequency, which is contrary to the hypothesis that enhanced seed have higher germination rates in all field conditions. The fact that 50% more enhanced seeds were used in the oversowing treatment did not contribute to a higher occurrence of grass species from the enhanced seeds, suggesting that factors other than enhancement

can also influence the germination and survival rate of seed oversown into a particular area. Furthermore, the overall frequency of the perennial grass species increased in the unsown control plots, suggesting that the rip plough treatment without oversowing of grass seed, had a positive effect for increasing the species richness in a degraded area, supporting work done by Adams (1996) and Edwards & Crawley, (1999). Favourable rainfall, which was higher than the average long-term rainfall, near the time of oversowing is another factor that had a positive influence on the increase of the frequencies of the grass species. In 1995, there were rainfall peaks in October and December. In 1996, 10 days prior to the oversowing treatment in February, the first of two peaks of rainfall occurred. These peaks together with the one in April 1996 attributed to the high number of oversown species that established. These established species further increased in numbers due to the high rainfall of January and March of 1997. When the water infiltration capacity of a soil has been improved with e.g. rip plough cultivation, that soil remains moist for a longer period than unripped soil (Davies *et al.*, 1986). The result is more productive vegetation. In the end, the condition of the cattle utilizing the improved pasture also picked up. The untreated seed of *C. ciliaris* had the highest density, supporting the findings of the frequency data. The results for the frequency and density data were very similar, i.e. an increase in especially *C. ciliaris* and *A. pubescens* over the four year period (1996-2000). The decrease of the species in 1999 to 2000 is linked with the removal of the fence and the subsequent pressure of grazing on the grass sward.

A. canescens was one of the dominant species prior to the treatment and is not palatable. This grass irritates the skin of the animals, but decreased after the treatment and was replaced with more desirable palatable species, e.g. *S. sphacelata* which would improve the cattle's condition, and increase their value on the market. The one factor that greatly attributed to the establishment of the perennial species is the above-ground rainfall experienced throughout the study period. It is interesting to note that none of these species, except *T. berteronianus* and *A. congesta* really achieved the same numbers as those compared with the untreated seed.

Plants from the untreated seed do not have this vigor benefit and species of the area have the freedom to utilize the aeration and water infiltration to increase their own populations. So, yes if seed is present in the soil seed bank, these will establish and increase their populations unless grass species that are enhanced are oversown. Also, the species that do stand a chance against the enhanced grasses are those with stronger structures, e.g. *U. panicoides* (roots) and *C. dactylon* (rhizomes).

Forbs and annual grass species formed the greatest component of the soil seed bank, clearly reflecting the vegetation that characterized the study area prior to any restoration application. This characterization corresponds to other studies by Akinola *et al.*, (1998), Bakker (2000) and Du Toit & Alard (1995). These results show that even in a degraded area characterized by eroded and scalded soil surfaces, the soil seed bank can be very rich and diverse. By applying any sort of restoration treatment, such as a simple cultivation method, the microhabitat conditions, such as soil moisture, can be improved greatly to enable these seeds to germinate and species to establish. As shown in this study, a drastic increase in species richness occurred for perennial, climax species such as *H. contortus*, *T. triandra* and *M. repens* after the application of a rip plough treatment. (The initial species composition see Section 3.3, Chapter 3, did not include any of the above mentioned species. Blumenthal (1999) found similar increases in species richness.

A DCA-ordination analysis revealed the trend in change in vegetation composition. Two plant communities, one dominated by *A. pubescens* and one by *C. ciliaris*, developed between 1996 and 2000 as a result of the restoration procedures applied. The study area was divided into four plots of which sub-plot one did not contain *A. pubescens*, but *C. ciliaris* and of which sub-plot 3 contained *A. pubescens* but not *C. ciliaris*. Thus these sub-plots developed towards dominance of the named species because the other species in the mixture decreased during the study period (Table 6.1 and Figs 6.4 and 6.5). Both were dominated by palatable, perennial grasses resulting in a marked increase in the condition of the range, production and grazing capacity of the study area. In conclusion, *A. pubescens* and *C. ciliaris* are useful species to consider for restoration practices in similar environment.

In the 1995/1996 season, the frequency of bare ground was greater than 50% and in the 1999/2000 season the frequency for bare ground was reduced to between 1% and 3%. A further conclusion, then, is that sheet erosion for this specific study area could be reduced using the rip plough cultivation method and sowing in of perennial climax grass mixtures that include untreated seed of *C. ciliaris* and *A. pubescens*.

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Chapter 7. The effect of restoration treatments on the vegetation in a degraded natural, semi-arid pasture (communal area Kromspruit)

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7.1 Abstract

Digitaria eriantha, *Chloris gayana*, *Cenchrus ciliaris* and *Panicum maximum* are perennial grasses used for restoration of vegetation cover to increase the production and condition of degraded areas. The dominant grass species in the degraded pasture was undesirable and annual grasses, such as *Chloris virgata*, *Urochloa mosambicensis*, *Cynodon dactylon* and *Aristida congesta*. Different mixtures of treated (enhanced) and untreated caryopses (hereafter called seed) of these grass species were oversown into part of a semi-arid pasture. A rip plough cultivation method was used to prepare the soil for the oversowing treatment.

The untreated seed (u) had the highest germination rate in the laboratory, but the enhanced seed (e) had the highest seedling survival under normal conditions in the field. Frequency of the sown-in grasses increased during the study period 1995-1999, and the density of the plants from enhanced seed decreased. The soil seed bank analysis corresponded with current literature and contained seed of *D. eriantha*, *C. gayana* and *P. maximum*. The frequency of *C. virgata*, *Eragrostis rigidior* and *C. dactylon* decreased due to the rip plough cultivation method. The number of individuals in the populations of the above mentioned three grasses decreased, and so did their relative contribution in terms of frequency to the plant community. The frequency and density of species such as *Brachiaria eruciformis* and *Bothriochloa insculpta* increased over the study period. A restorative or succession gradient exists on the first axis of the DCA ordination. The vegetation composition changed from a pioneer dominated community to a *D. eriantha*-*Eragrostis lehmanniana* community. The grass species richness increased from 11 species in 1996/1997 to 25 species in 1998/1999.

The suitable grass mixture recommended for restoration for this clayey soil type is *D. eriantha*, *P. maximum* and *C. ciliaris*. The rip plough cultivation method and sowing in of perennial, climax grass mixtures can greatly enhance natural succession in degraded areas.

Additional index words: rangeland restoration, communal farming, perennial grasses, rip plough cultivation, DCA ordination.

7.2 Introduction

Rangeland degradation in the communal areas of South Africa is mainly the result of overgrazing combined with drought (Kellner, 1995; Milton & Dean, 1995). Overgrazing causes a decline in the vegetation cover and density of perennial grasses to leave predominantly annual grass species of poor forage quality (Kellner, 1995; Van Oudtshoorn, 1999). Land-users in rural communities seldom perceive the poor veld condition as a problem and must be alerted to the disadvantages of a non-resilient annual plant community. Their attention must also be focussed on the overall decline in vegetation condition and its negative impact on sustainable natural resources (Haro *et al.*, 1996; Hodgson & Illius, 1996; Hoffman *et al.*, 1999).

According to Darkoh (1986), anti-degradation programs in southern Africa include several strategies ranging from international to community involvement, such as resettlement and reclamation teams for projects beyond the ability of local communities. Other anti-degradation and desertification programs include the promotion of game ranching, afforestation projects, the integration of forestry and agriculture, the development and improvement of irrigation and water resources and the implementation of new or alternative energy sources, e.g. solar cookers, etc. The community of Kromspruit was involved in the establishment of the study areas. This increased their awareness of degradation, as well as of solutions available for degradation problems.

Milton *et al.* (1998) addressed non-sustainable pastoralism in the Karoo with the health assessment method that encourages regular evaluation of the rangeland, the use of multiple rangeland resources and an awareness of biodiversity. Other systems that can be used to assist the land user in developing long-term, sustainable management systems, include software packages such as the Integrated System for Plant Dynamics (ISPD) (Bosch *et al.*, 1992) and data base expert systems (Van der Merwe, 1997). These systems supply the land manager with different options for restoration technologies, including organic, biological and mechanical methods (Van der Merwe, 1997). These restoration techniques include specified debushing (Cairns, 1995), gypsum addition, ripping, pitting and re-seeding (Tainton, 1999) using locally available implements (Call & Roundy, 1991; Cairns & Heckman, 1996; Dobson *et al.*, 1997; Milton *et al.*, 1998). Another important

method is the use of demonstration plots within the communal areas to convince communities to adopt the technologies.

Another aspect of restoration that must be considered is the soil seed bank of the degraded area. Available seed in the soil will germinate after mechanical restoration techniques are applied. This germination of seed from the soil seed bank could influence the dynamics of species that are re-seeded in either a positive or a negative way (Akinola *et al.*, 1998a; Akinola *et al.*, 1998b; Bekker *et al.*, 1998; Bertillier, 1996; Lyaruu, 1999). For example, vigorous perennial grasses such as *Setaria sphacelata* may compete with *C. gayana* and repress the latter species. If the latter species is one sown into the area for restoration purposes and its growth is repressed, the sown in species contribution to the vegetation composition and thus to the restoration effort can be minimized.

Degraded grazing lands in the North West Province in South Africa and particularly in the study area of Kromspruit in the previously known Madikwe, but currently Mankwe District was used as a testing ground for the rip plough cultivation technique combined with oversowing of perennial climax grass species. The aim was to establish the sustainability of the resulting grass populations (Ellis & Swift, 1988; Gliessman, 1995; Gliessman, 1998) and comparing it to the soil seed bank to determine the success of the particular species' reproduction.

7.3 Materials and methods

7.3.1 Study area

The study area is situated on the farm Kromspruit, 20 km northwest of the town of Madikwe (26°30'S, 25°22'E) in the North West Province (South Africa) (Fig. 7.2, Cartographic and GIS Services²). At an altitude of 945 m above sea level (Land Type Survey Staff, 1984b) the study area is adjacent to the Maretlwana River (Department of Water Affairs and Forestry³). Situated in the Savanna Biome

² ☒ Dept. of Geography and Environmental Study: Cartographic and GIS Services, Internal Box 317, PU for CHE, Potchefstroom, 2520.

³ ☒ Department of Water Affairs and Forestry, P/bag X 6001, Potchefstroom, 2520.

(Rutherford & Westfall, 1994) this Bankenveld Veld Type (Acocks, 1988) is characterised by Clay thorn bushveld (Bredenkamp *et al.*, 1996).

The vegetation composition was primarily characterised by species of poor ecological status, such as *C. virgata* (Van Oudtshoorn, 1999) as well as several *Acacia* spp. forming thickets. The long-term rainfall of the area is 577 mm per year. Between 1994 and 1997 an average of 310 mm per year was recorded. The minimum temperature between 1995 and 1999 was -4.5 °C. The maximum temperature for the period 1995 to 1999 was 38.1 °C. The long-term average temperature is depicted in Fig. 7.1. AgroMet⁴ supplied the average long-term rainfall (20 years ending 1989), short-term rainfall (1995-1999) and temperatures.

The soil is a black vertic clay (20 - 35%, Dept. of Conservation and Environment⁵; Bredenkamp *et al.*, 1996) overlain with a yellow-red sand to the southern side of the study area. The texture is a sandy clay loam soil with pH_{H2O} between 7.43 and 7.97. The soil has poor drainage and aeration (Bruce, 1998).

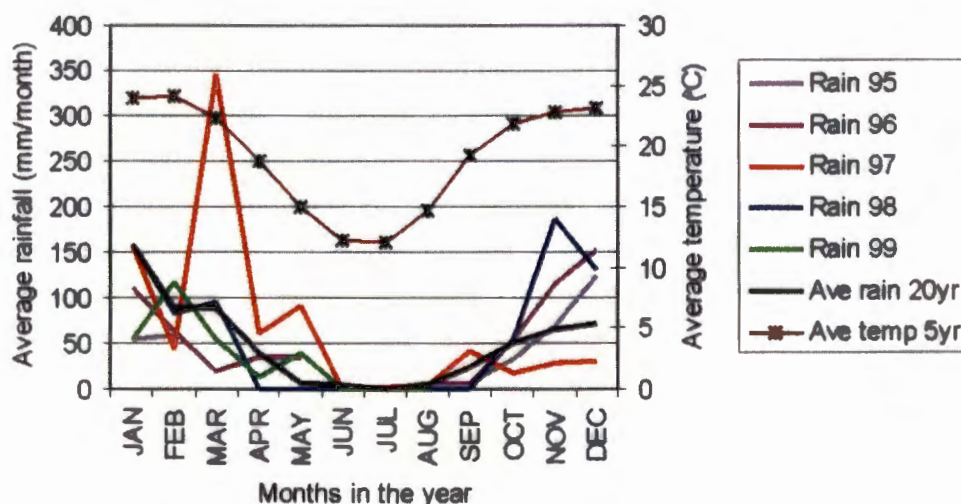
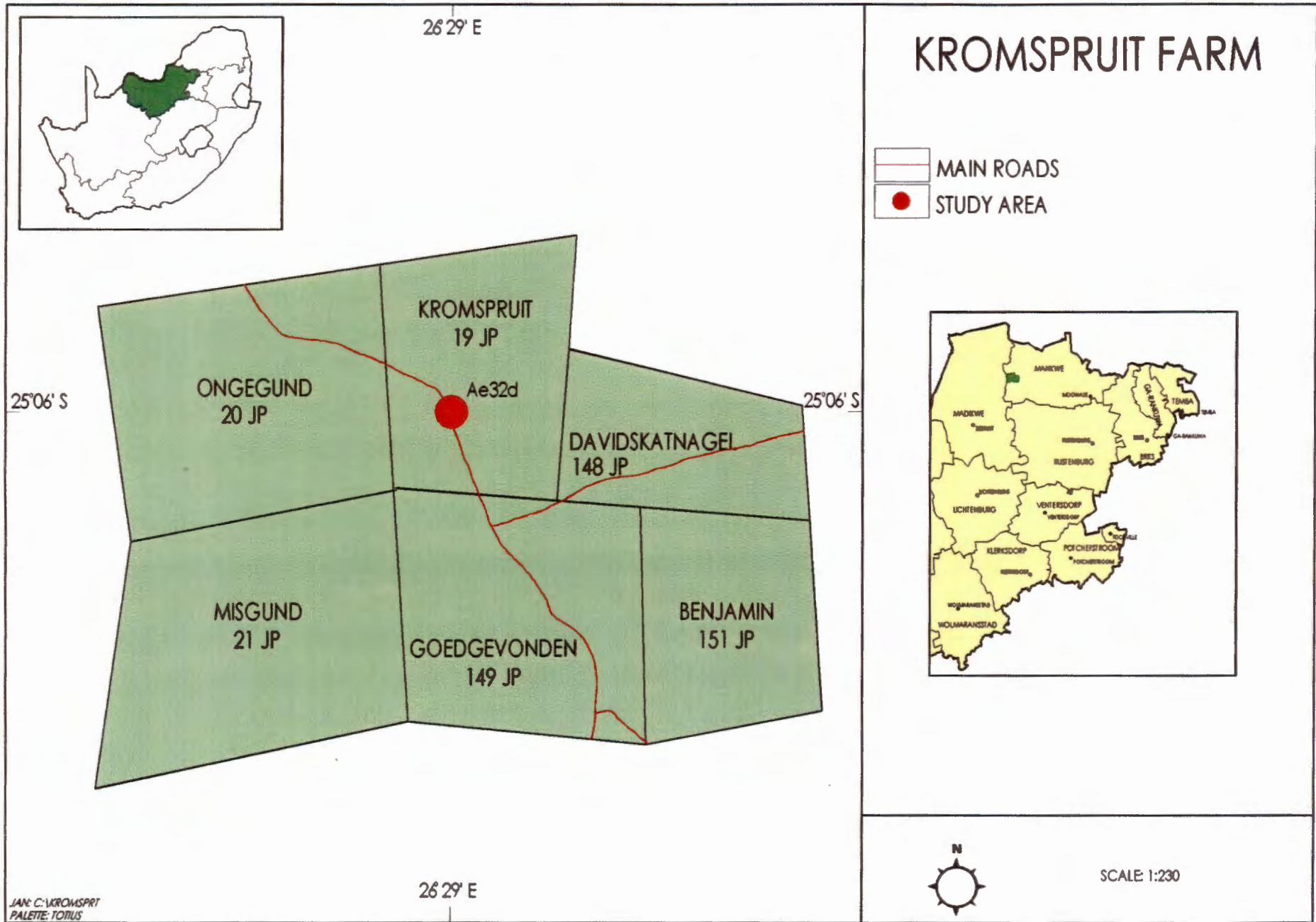


Figure 7.1: The average long-term (20 yrs) and short-term (1995 - 1999) rainfall and temperature (°C) for the Kromspruit study area.

⁴ AgroMet Potchefstroom, Institute of Soil, Climate and Water, P/b x1251, Potchefstroom, 2520.

⁵ Department of Conservation and Environment: Geology, P/bag X 804, Potchefstroom, 2520.

Figure 7.2: The location of the Kromspruit study area in the North West Province of South Africa (supplied by Dept. of Geography and Environmental Study: Cartographic and GIS Services)



7.3.2 Restoration treatment

The restoration process for this area entailed the rip plough cultivation method (Tainton, 1981; Van der Merwe, 1997). Soil was ripped to a depth of 150 mm with the plough rows 800 mm apart. Seed of the perennial grass species (native to the geographic area, except *C. gayana* that was naturalised from India) were sown by hand into the furrows and slightly covered with soil. The grass species used were *D. eriantha*, *C. ciliaris*, *C. gayana* and *P. maximum*. The total area treated in this way occupied 7500 m² and was then divided into a total of 21 sub-plots (as defined in Chapter 2) with one serving as a control. The size of each sub-plot was 70 m x 5 m. The study area was fenced to withhold all grazing by large herbivores. A control plot outside the enclosure was still heavily grazed. The 20 sub-plots were divided into 10 samples oversown with enhanced seed and 10 sown with untreated seed (see Section 2.3 in Chapter 2).

The 10 sub-plots sown with enhanced seed were divided into five sub-plots sown with the mixtures shown in Table 7.1 (sub-plot 1-5). The other five sub-plots sown with enhanced seed had 50%. Sub-plots 6-10 were repeated twice for the 10 sub-plots sown with untreated seed. The seed densities are according to the recommendation of Advance Seed Co. (Pty) Ltd.⁶ in order to compensate for competition, as well as the ratio between weight and number of seed in 1kg of enhanced and untreated seed.

7.3.3 Field sampling methods

Vegetation surveys were carried out during February/March in the growing seasons, of 1997 to 1999. In each sub-plot the frequency of all the grass species was determined through the wheelpoint method (nearest plant recording) (Tidmarsh & Havenga, 1955). For each sub-plot approximately 100 (never less than 89 and never more than 112) points were recorded (see Section 4.3 in Chapter 4).

⁶ ☒ Advance Seed Co. (Pty) Ltd., Box 414, Krugersdorp, 1740, ☎ +27 11 762 5261 (o), +27 11 762 4111

Table 7.1: The average weight (in kilogram/hectare) of seed sown in the different sub-plots (sub-plots 1-5 had enhanced seed, the second set of sub-plots was sown with twice as much and sub-plots 6-10 had untreated seed) and the average number of seed per gram (in brackets) at the Kromspruit study area. Abbreviations of the species were used throughout

Species	Treatment	Sub-plot 1 kg/ha (no. of seeds per gram	Sub-plot 2 kg/ha (no. of seeds per gram	Sub-plot 3 kg/ha (no. of seeds per gram	Sub-plot 4 kg/ha (no. of seeds per gram	Sub-plot 5 kg/ha (no. of seeds per gram
<i>Digitaria eriantha</i> D.eri	Enhanced	0.8 (981)	1.5		1.5	
	Enhanced (+50%*)	1.5 (1962)	3		3	
<i>Panicum maximum</i> P.max	Enhanced	0.8 (546)	1.5	1.5		1
	Enhanced (+50%*)	1.5 (1092)	3	3		2
<i>Chloris gayana</i> C.gay	Enhanced	0.8 (646)			1.5	1
	Enhanced (+50%*)	1.5 (1292)			3	2
<i>Cenchrus ciliaris</i> C.cil	Enhanced	1.3 (105)		1.5		1.7
	Enhanced (+50%*)	2.6 (210)		3		3.4
		Sub-plot 6	Sub-plot 7	Sub-plot 8	Sub-plot 9	Sub-plot 10
D. eri	Untreated	7.5 (2655)	1.5		1.5	
P. max	Untreated	0.8 (1994)	1.5	1.5		1
C. gay	Untreated	0.8 (3778)			1.5	1
C. cil	Untreated	1.3 (399)		2.6		1.7

* - 50% more seed

A quadrat (1 x 1 m) was placed randomly in each sub-plot to determine the density and growth stages of each grass species (Brown, 1957). A replicate of three quadrats per sub-plot was monitored. Three different growth stages were noted.

Established seedling and/or tillers (a plant with one shoot protruding from the ground as in the case of *C. gayana*), vegetative mature plant (having more than one shoot protruding from the ground) and reproductive plant (clearly bearing reproductive organs or the remains of it) were noted. The number of surviving seedlings sampled during the second year (1997/1998) after the restoration application is used in the calculation. This number of surviving seedlings is compared to the first year's (1996/1997) laboratory germination rate. The presence of all three growth stages in this study is regarded as an indication of a healthy, sustainable population.

7.3.4 Soil seed bank analysis

Soil samples were collected for the soil seed bank analysis in the summer period of 1998/1999. Three soil samples per grid were collected with a soil auger (approximately 1006 cm³, Du Toit & Alard, 1995) and allowed to air dry for two weeks. The three samples of each sub-plot were combined (approximately 3017 cm³) in a 300 mm x 200 mm x 80 mm (4800 cm³) seed tray. The samples were greater than the 100 cm³ soil sample in each 1 x 1 m plot that Tsuyuzaki & Kanda (1996) used. Seed germination rates were determined by the germination of the seeds in the soil samples (Tsuyuzaki & Kanda, 1996). The analysis was conducted in a greenhouse where the temperature varied from 28 °C day to 20 °C at night. The soil was kept moist (Du Toit & Alard, 1995; Schrautzer *et al.*, 1996). The species were allowed to germinate (first appearance of the radicle and the plumula according to Weinbrenn, 1946) and left until identification was possible. Where two or more of the same species germinated, all but one specimen were removed to reduce seedling competition for nutrients. Identified species were also removed. The results of the soil seed bank analysis were noted and compared to the standing grasses of the study area. A period of 150 days is sufficient for only 2% of seed to remain in the soil (O'Connor & Everson, 1998).

Seedling density of the soil seed bank analysis per 1 x 1 m x 0.02 m was calculated as follows:

Three samples of >1006 cm³ soil add up to 4800 cm³ (amount of soil fitted into 300 mm x 200 mm x 80 mm containers). That is converted to 1 x 1 m x 0.02 m, as a measurement of the seedling density per square meter in the field.

For example, 14 seedlings germinated from a seed tray. Converting the number of seedlings/cm³ to the number of seedlings/1 x 1 m x 0.02 m (20 000 cm³ is the conversion factor):

$$\begin{aligned} & \frac{14 \text{ seedlings}/4800 \text{ cm}^3 \times 20\,000 \text{ cm}^3}{4800 \text{ cm}^3} \\ \text{or } & \frac{14 \text{ seedlings}/0.0048 \text{ m}^3 \times 0.02 \text{ m}^3}{0.0048 \text{ m}^3} \\ & = 58.3 \text{ seedlings}/0.02 \text{ m}^3 \\ & \text{or } 58.3 \text{ seedlings}/1 \text{ x } 1 \text{ m x } 0.02 \text{ m} \dots\dots\dots 7.1 \end{aligned}$$

7.3.5 Germination tests

The germination rates of the seed oversown in the field experiment was tested in the laboratory under optimal conditions. Ten seeds per species were placed in containers, 10 ml of distilled water was added to each, and the containers were sealed to avoid moisture loss (see Section 9.11, Chapter 9). The trials were carried out at 25 °C for 28 days in a Gallenkamp Plus II incubator (Monitoring and Control Laboratories (Pty) Ltd⁹). The number of seed that germinated was noted as the germination rates of the given species and compared to the seedling survival rate under natural conditions in the field experiments. Impurity values of the seed batches were determined according to the regulations of International Seed Testing Association (ISTA⁸).

7.3.6 Data analysis

Averages of the frequency and density data of the grass species in the restored sub-plots were calculated in the following manner:

⁹ ☒ Monitoring and Control Laboratories (Pty) Ltd, Box 890226, Lyndhurst 2106, ☎ + 27 11 483 3149 (o), + 27 11 483 2146 (f)

A given weight of seed was sown per area. Impurity values were subtracted from the specific weight, resulting in the weight of potential seed that would germinate (according to ISTA procedures). The number of seed per grams sown into the sub-plots was compared to the number of seed sown-in and the number of plants surviving after the first season. The nonparametric distribution of all the data necessitates the use of specific statistical parameters such as analysis of variance.

The quantitative data were analysed statistically using the ANOVA/MANOVA technique in the STATISTICA for Windows (StatSoft, Inc., 1999) computer program. The purpose was to find significant differences between the types of seeds sown and the germination rates of seed and seedling survival rates. Results were considered statistically significant if $p < 0.05$, except were otherwise indicated. The Spearman rank correlation method was also used (Steyn *et al.*, 1995).

Using multivariate analysis methods, such as DECORANA (Hill, 1979), the change of species' composition over time was determined by trajectories on a gradient. DCA ordination was used for the gradient analysis which was conducted in Integrated System for Plant Dynamics (Bosch *et al.*, 1992).

7.4 Results

7.4.1 Seed germination rates, seedling survival and grass mixtures

The untreated seed, specifically *C. ciliaris* (48%) and *C. gayana* (39%), had the highest germination rate in the laboratory ($p = 0.00$, Table 7.2, Fig. 7.3). In the field where the seed was sown in a 1:1 ratio (enhanced : untreated), the seedling survival of the untreated seed was higher than seedling survival of the enhanced seed (Fig. 7.4). In the trials where 50% more enhanced seed was used, the enhanced seed had a significantly ($p = 0.00$, Fig. 7.4, Table 7.2) higher seedling survival rate.

In sub-plots 1 and 6, only *D. eriantha* seedlings survived (Table 7.1, Fig. 7.5, no. 1, Fig. 7.6, no. 1 and Fig. 7.7, no. 6).

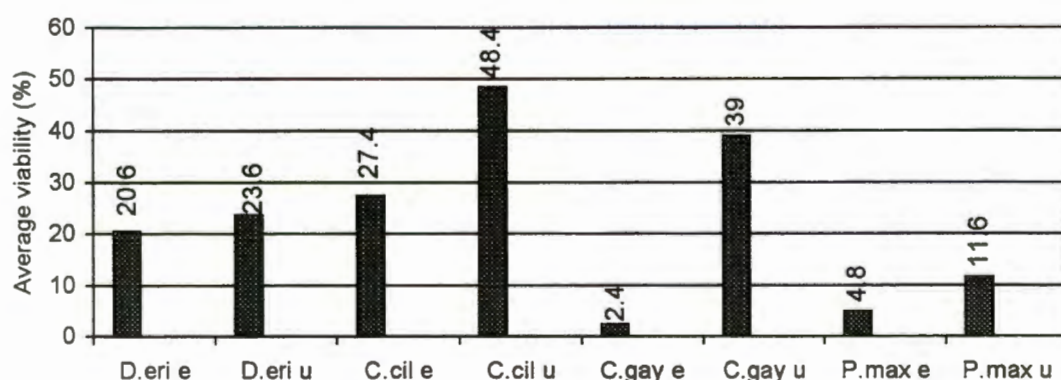


Figure 7.3: The average germination rate per number of seed under optimum conditions in the laboratory of the enhanced (e) and untreated (u) seed of the grass species sown in the field trials at Kromsprit ($p = 0.00$).

Table 7.2: The analysis of variances (p-value) for the Kromsprit study area based on the Scheffe test (* indicates significant differences)

	Sub-plot	Species	Seed treatment (e and u)	Year	Growth stage	No. in laboratory and field
Frequency	0.27	0.01*	0.00*	0.53	1.00	1.00
Density	0.27	0.12	0.02*	0.02*	1.00	1.00
No. of seedling, vegetative and reproductive stages	0.27	0.00*	0.75	0.00*	0.03*	
No. of seed	0.27	0.65	0.00*			0.00*

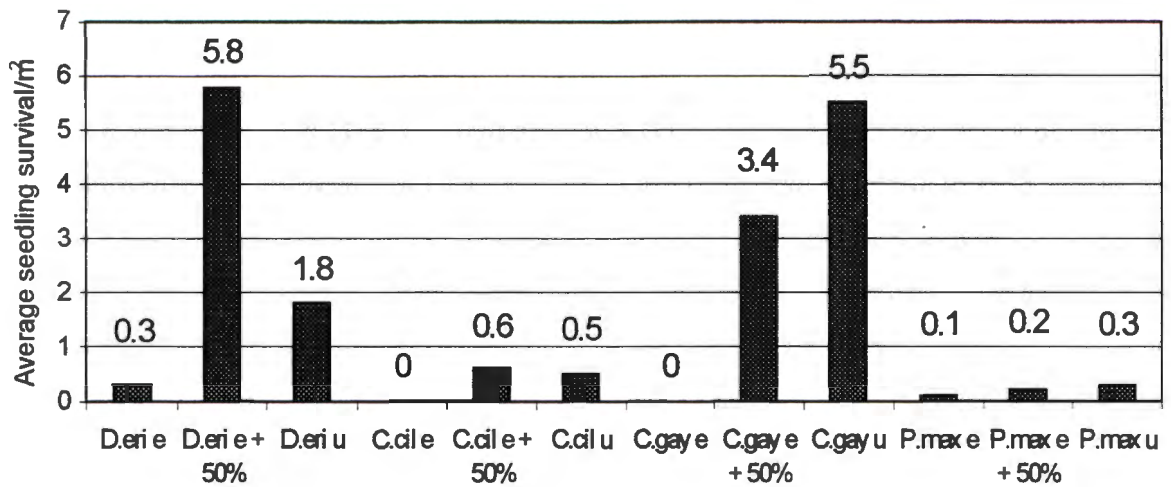


Figure 7.4: The average number of the seedlings surviving from the enhanced (e), e + 50%, and the untreated (u) seed sown in the field trials at Kromspruit (ripped 150 mm deep).

In the 15 days before the sowing of the seed, a rainfall event of 80 mm occurred. 19 seedlings/m² of all the seed sown in 1995 survived, with the higher seedling survival being *D. eriantha* from the enhanced plus 50% more seed, (Figs. 7.4, 5.8). *C. gayana* from the untreated seed had 6 seedlings/m² surviving (Figs. 7.4, 5.5) and *C. gayana* from the enhanced plus 50% more seed had 3 seedlings/m² surviving (Figs. 7.4, 3.4).

Figures 7.5 to 7.7 depict the number of individuals sown for each grass mixture as well as the percentage of individuals that germinated in the laboratory and the percentage of seedlings that survived in the field for the enhanced, enhanced plus 50% more seed and the untreated seed.

The laboratory germination rate *C. ciliaris* for untreated seed used in sub-plot 6 (48.8%, Fig. 7.7) was highest followed by the enhanced plus 50% more seed (27.4%, Fig.7.6). There is a marked correlation between the different species and their field seedling survival ($R = -0.8$). In all three treatments of mixture 1, only *D. eriantha* seedlings survived in the field (Table 7.1; Fig. 7.5 to Fig. 7.7). The untreated seed of *D. eriantha* had the highest percentage of individuals surviving in

the field (1%, Fig. 7.7). Of the four species used in sub-plot one, *D. eriantha* is the one species adapted to the widest range of habitats (Van Oudtshoorn, 1999) and has a unique method of coping with the occurrence of soil shrinking and stretching. *D. eriantha* sown at Kromsprit formed a dense mat of stoloniferous growth.

There is no marked correlation for sub-plots 2 (Figs. 7.5 and 7.6) and sub-plot 7, where a mixture of *D. eriantha* and *P. maximum* was used (Fig. 7.7). The untreated seed had the higher germination rate of the treatments (24 and 12%, Fig. 7.7, no. 7). *P. maximum* seedlings survived in sub-plot 2 sown with the enhanced seed (Fig. 7.5), but not in the sub-plot 2 sown with enhanced plus 50% more seed (Fig. 7.6) or in sub-plot 7 sown with untreated seed (Fig. 7.7). Throughout this study untreated seed had low survival rates in the field, and at Kromsprit the enhanced plus 50% more seed were sown in the part of the study area where the clay soil was not covered with sand. The enhanced plus 50% more seed would have to germinate on a soil that shrunk and stretched rapidly according to the available soil moisture (Rowell, 1994). This clay soil is detrimental to root penetration (Barbour *et al.*, 1987). *D. eriantha* seedlings survived in sub-plot 2 sown with 50% more seed (Fig. 7.6) and in sub-plot 7 sown with untreated seed (Fig. 7.7).

There is a marked correlation between the treatments in the field and the germination rate in the seed ($R=0.837$) sown in sub-plot 3 (Fig. 7.5 and 7.6) and sub-plot 8 (Fig. 7.7), especially between the two enhanced treatments (Fig. 7.5 and 7.6). Both sub-plots 3 and 8 were sown with a mixture of *P. maximum* and *C. ciliaris*. Once again the untreated seed had the higher germination rate in the laboratory (48%, Fig. 7.7). If *P. maximum* and *C. ciliaris* are compared, *C. ciliaris* had the higher seedling survival (2%, Fig. 7.6), especially for the enhanced plus 50% more seed as stated previously. There is a marked correlation between the number of seed sown and the laboratory germination rate ($R=0.837$) of sub-plots 4 (Fig. 7.5 and 7.6) and sub-plot 9 (Fig. 7.7).

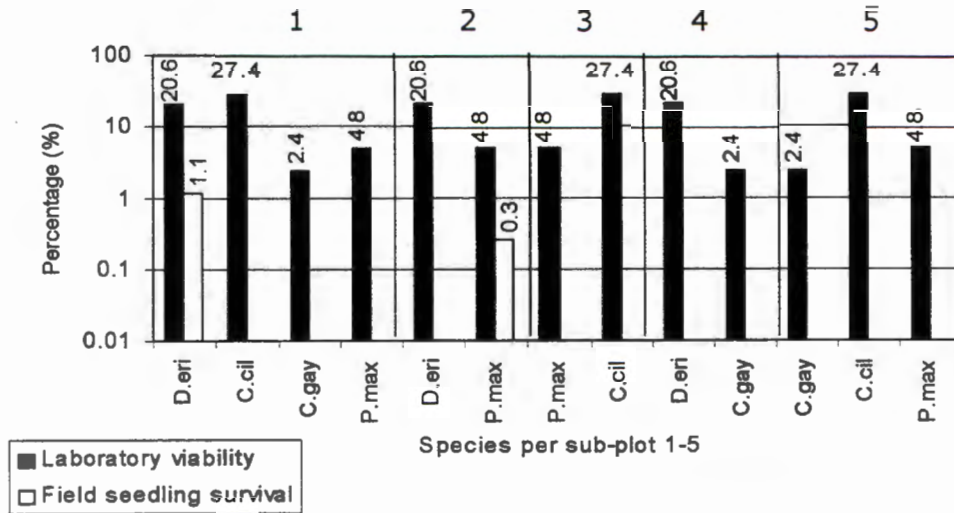


Figure 7.5: The restoration treatment where enhanced seed was used at Kromspruit: a comparison between the germination rate of the seed in the laboratory and the percentage of seedlings of sub-plots 1 to 5 (see Table 7.1) that survived in the field.

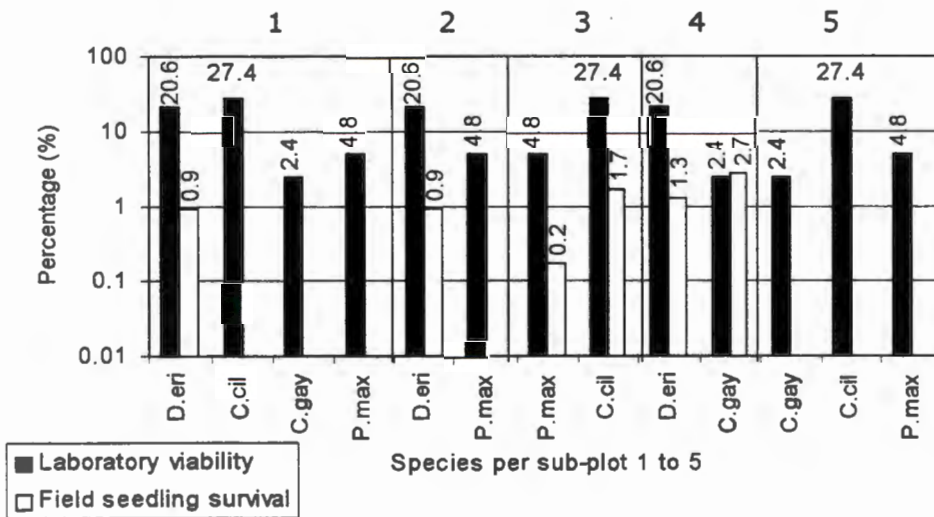


Figure 7.6: The restoration treatment where enhanced + 50% more seed was used at Kromspruit: a comparison between the germination rate of the seed in the laboratory and the percentage of seedlings that survived in the field in sub-plots 1 to 5 (see Table 7.1).

In sub-plots 4 and 9 a mixture of *D. eriantha* and *C. gayana* was used. The untreated seed had the highest number of seed germinating for both *D. eriantha* and *C. gayana* in the laboratory (39%, 23.6%, respectively, Fig. 7.7). There is no marked correlation for the field seedling survival of the different treatments and, therefore, it is presumed that their survival in the field did not differ significantly (Table 7.2, $p = 0.75$). The enhanced plus 50% more seed treatment resulted in the highest number of seedlings in the field (3%, Fig. 7.6, no. 4). None of the enhanced seed survived in the field (Fig. 7.5), but *D. eriantha* and *C. gayana* survived in the plots sown with enhanced plus 50% more seed. For the untreated seed, only *C. gayana* survived in the field (1%, Fig. 7.7).

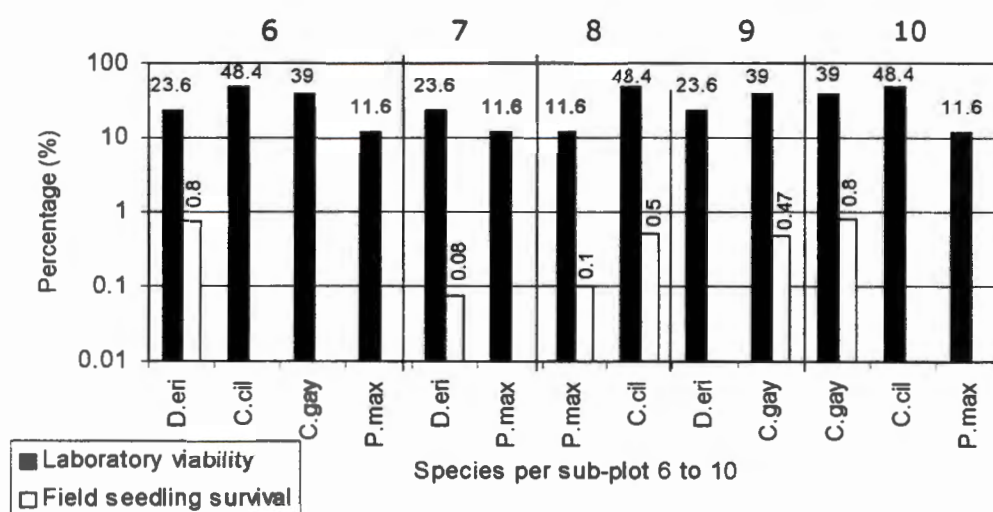


Figure 7.7: The restoration treatment where untreated seed was used at Kromspruit: a comparison between the germination rate of the seed in the laboratory and the percentage of seedlings that survived in the field in sub-plots 6 to 10 (see Table 7.1).

A marked correlation exists between the number of seed sown and their germination rate in the laboratory ($R=0.791$) for sub-plots 5 (Fig. 7.5 and 7.6) and sub-plot 10, where a mixture of *C. ciliaris* and *P. maximum* was used (Fig. 7.7). The untreated seed had the highest germination rate in the laboratory (48%, Fig. 7.3). Only untreated *C. gayana* survived in the field (1%, Fig. 7.7). The germination rate and seedling survival rate does not match the frequency data. Species that had less

than one germination rate or seedling survival were not presented in the figures because species do not occur as less than one individual in the field.

7.4.2 Frequency and density of oversown species

The average frequency of the different grass species sown in differs significantly for the enhanced (p = 0.01) and untreated seed (p = 0.00, Table 7.2). None of the species sown-in occurred in the study area at the time of restoration. The average frequencies of the sown-in species increased from 0% to values as high as 24% for *D. eriantha* and 15% for *P. maximum* (Fig. 7.8 and Table 7.3) in three years. During the period 1996 to 1998, all of the sown-in grass species increased (Fig. 7.8).

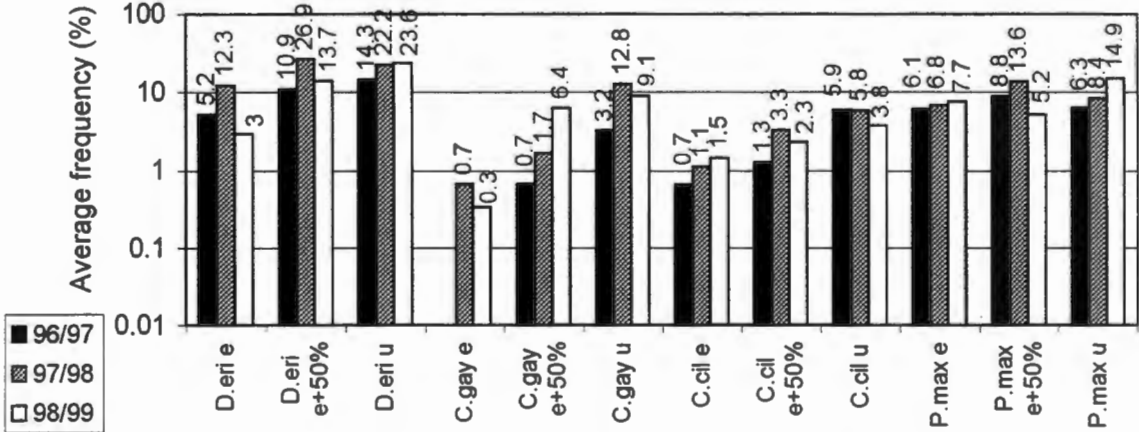


Figure 7.8: The average frequency of the sown-in grass species over a three year period, enhanced (e), enhanced plus 50% of recommended density and untreated (u) seed was sown in a rip plough furrow 150 mm deep.

For the year 1998/1999 with a lower than average rainfall, almost all the grass species decreased, except for *D. eriantha* where untreated seed was used (22% to 24%), *C. gayana* (enhanced + 50% more seed - 2 to 6%), *C. ciliaris* (enhanced

seed - 1 to 2%), *P. maximum* (enhanced seed - 7 to 8%) and *P. maximum* (untreated seed - 8 to 15%). It is argued that if the cohort of *D. eriantha* (e) is greater than that of *D. eriantha* (u) in the first year, then the population from former will continue to be greater in the following years. The former population theoretically contributed more individuals each with the potential of contributing seed and seedlings. When enhanced and untreated seed are oversown under similar field conditions and the enhanced seed forms a cohort of more individuals, the population arising from the enhanced seed will keep on being more numerous than the populations arising from the untreated seed.

On the other hand, if the frequency data are compared to the density data, then all the species decreased, except where both the enhanced and untreated seed of *D. eriantha* were used, as well as untreated seed of *C. ciliaris* and treated and untreated seed of *P. maximum* (Fig. 7.10). The average density of the grass populations for the enhanced and untreated seed differs significantly between the two years ($p = 0.02$, Table 7.2).



Figure 7.9: The Kromsprit study area was cleared of bushes in the summer of 1995/1996 and rip ploughed before seed was oversown.



Figure 7.10: The study area at Kromsprit one year after bush clearing and restoration with an oversowing and rip plough treatment.

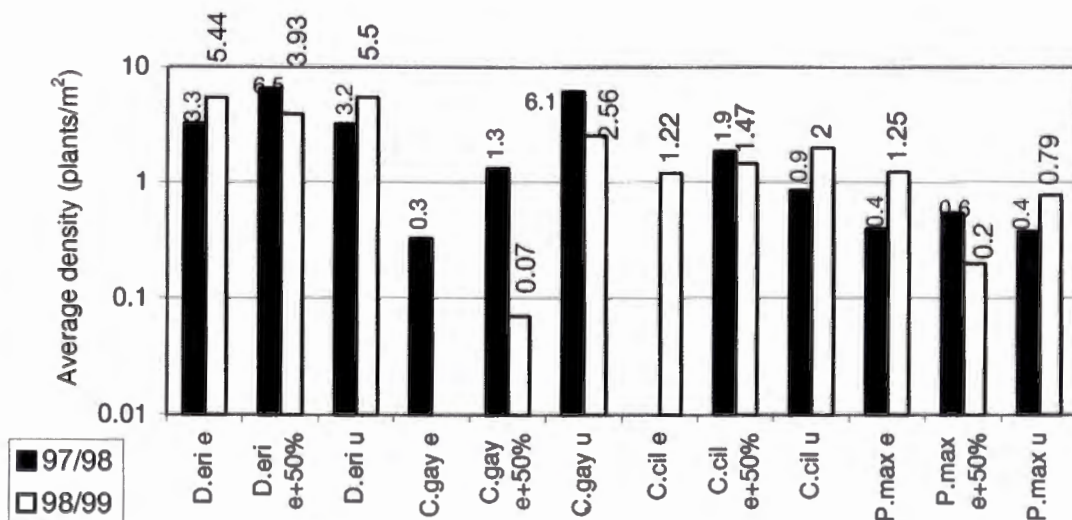


Figure 7.11: The average density of sown-in grass species over a four year period, enhanced (e) and untreated (u) seed sown in a rip furrow 200 mm deep.

A comparison between the rainfall and frequency data showed the following interesting results. Vegetation surveys were carried out in February 1997 and 1998, and March 1999. The average short-term rainfall for February 1997 and 1998 was below the average long-term rainfall for February. The average short-term rainfall for March 1999 was also below the average long-term rainfall for March, but the average short-term rainfall of the previous month, February 1999, was above the average long-term rainfall. The surveys of 1997 and 1998 occurred before the large peak of rainfall in March 1997 and 15 days after the peak of rainfall in January 1997, explaining the increase in the frequency of all the sown-in species between 1997 and 1998 (Fig. 7.8).

The average short-term rainfall of March 1999 was lower than the average long-term rainfall of March, and was forgone by a higher than average long-term rainfall for February (25 days prior to the survey). The decrease in average rainfall was reflected in the average frequency of *D. eriantha* (enhanced and enhanced plus 50% more seed, Fig 7.8). On the other hand, the survey method played a role in the differences between the number of plants from the enhanced and the plants from the untreated seed. On the other hand the frequency of *D. eriantha* (untreated) responded quickly to the high rainfall 25 days prior to the survey. The same type of reduction in numbers applied for *C. gayana* (enhanced and untreated seed), *C. ciliaris* (enhanced plus 50% more seed and untreated seed) as well as *P. maximum* (enhanced plus 50% more seed) (Fig. 7.8).

7.4.3 Growth stages

The number of seedlings as well as plants in the vegetative and reproductive growth stages of the grass species differ significantly from one another ($p = 0.03$, Table 7.2). In sub-plot 1 (Fig. 7.11, no. 1), the only species that was represented in all three growth stages was *D. eriantha* from the untreated seed (Fig. 7.11) as well as *C. gayana* of the 50% more enhanced seed (Fig. 7.13).

The other species that occurred in all three growth stages were *C. ciliaris* (untreated seed, in sub-plot 3, Fig. 7.11 and enhanced plus 50% more seed, in sub-plot 3, Fig. 7.13), *C. gayana* (untreated seed, sub-plots 4 and 5, Fig. 7.11) and *P. maximum* (enhanced plus 50% more seed, sub-plot 3, Fig. 7.13).

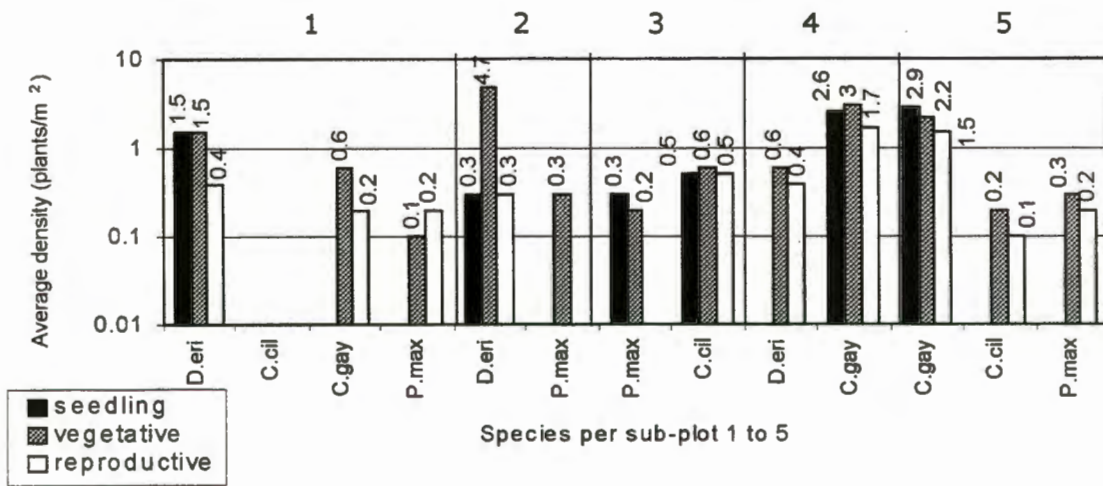


Figure 7.12: The average density of the growth stages of each of the sown-in mixtures in the sub-plots sown with untreated seed at Kromspruit. Abbreviations used appear in Table 7.1.

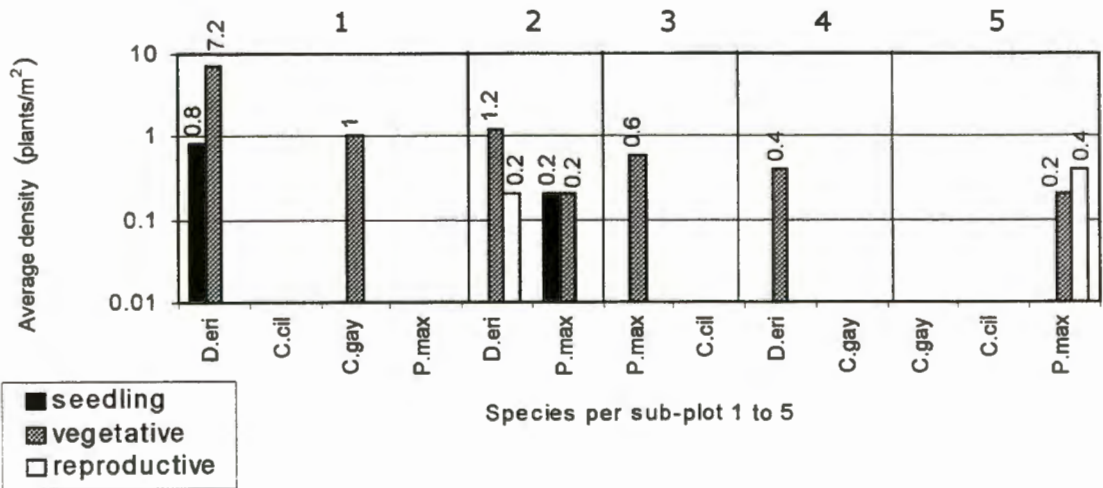


Figure 7.13: The average density of the growth stages of each of the sown-in mixtures in the sub-plots sown with enhanced seed at Kromspruit.

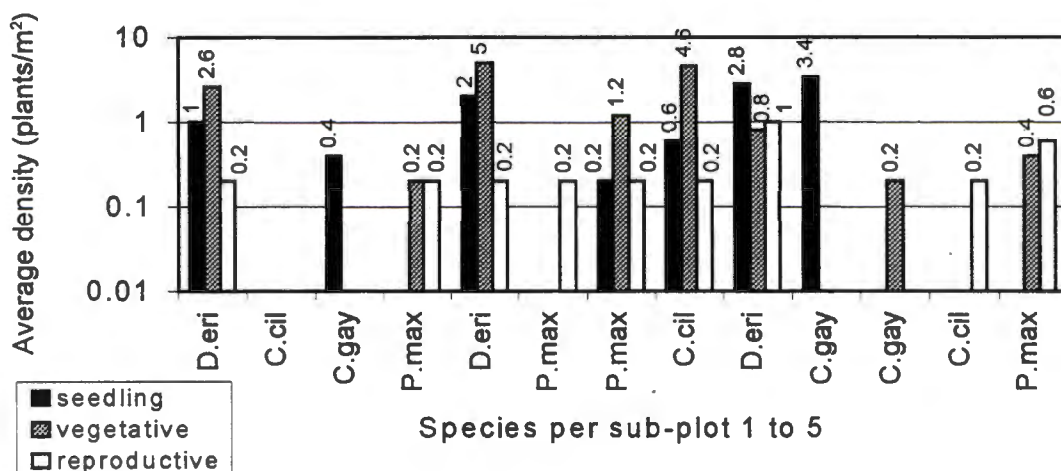


Figure 7.14: The average density of the growth stages of each of the sown-in mixtures in the sub-plots sown with enhanced plus 50% more seed at Kromspruit.

7.4.4 Soil seed bank analysis

In accordance with Du Toit & Alard (1995), Akinola *et al.*, (1998a & b) and Blumenthal (1999), the species richness in the soil seed bank was very high. A total of 571 seedlings of 32 species germinated from the soil samples during the soil seed bank analysis. The total seedling density varied considerably (50-221 seedlings/1 x 1 m x 0.02 m). The grass *Brachiaria eruciformis* dominated the soil seed bank. Of the sown-in species only *C. gayana*, *D. eriantha* and *P. maximum* were represented in the soil seed bank. The composition of the soil seed bank was 34% grasses (22% annuals and 13% perennials) 3% geophytes and 53% forbs (Fig. 7.14).

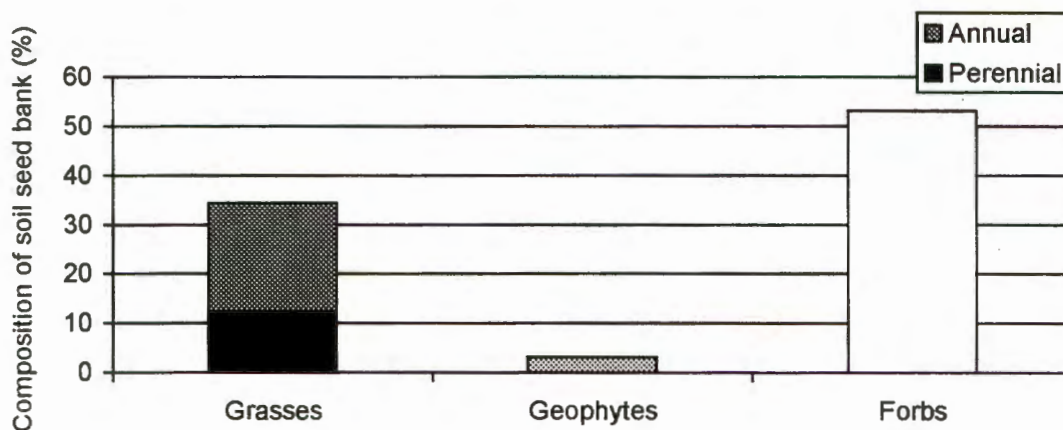


Figure 7.15: The composition of the soil seed bank of the different plant types at Kromsprit (summer 1998/1999).

7.4.5 Differences between the control and the oversowing treatments

When comparing the sub-plots sown with the enhanced and untreated seed with the control plot three years after the restoration application (Table 7.3), it is evident that the rip plough cultivation method especially benefited *D. eriantha*. In the sub-plots sown with the untreated seed, the frequency of *D. eriantha* has increased (14% in 1996 to 24% in 1999, Table 7.3), while it decreased in the plots sown with enhanced seed (5% in 1996 to 3% in 1999, Table 7.3). *C. gayana* did not spread into the control plot like *D. eriantha*, and decreased for both the untreated and enhanced treatment, whereas in sub-plots sown with enhanced plus 50% more seed *C. gayana* increased. *C. ciliaris* was not present in the control plot, decreased in the sub-plots sown with untreated seed and increased in the sub-plots sown with enhanced seed. *P. maximum* increased in all the sub-plots, except the enhanced plus 50% more seed. *C. virgata* increased in the sub-plots sown with enhanced seed and in the control plot, but decreased in the sub-plots sown with untreated seed, which is where most of the other perennials increased. *Eragrostis rigidior* benefited from the rip plough treatment only in the control plot. *U. mosambicensis* decreased in all the plots. *Eragrostis lehmanniana* (Lehmann's love grass) was absent in the control plot, increased in the sub-plots sown with enhanced seed and decreased in the sub-plots sown with untreated seed. *Brachiaria eruciformis* (sweet signal grass, an annual grass) decreased throughout the experiment. *Setaria nigrirostris*

decreased in the sub-plots sown with untreated seed as well as the control plot, but increased in the sub-plots sown with the enhanced seed. *A. congesta* increased in all the plots. In the sub-plots sown with enhanced seed, *Eragrostis curvula* (weeping love grass) and *Brachiaria serrata* (velvet signal grass) increased, while *Aristida diffusa* (iron grass) and *Tragus berteronianus* (carrot-seed grass) decreased. A species that increased only in the control plot is *Bothriochloa insculpta* (Table 7.3).

Differences also exist between densities of the grass species in the sub-plots treated with the rip plough, sown with enhanced, enhanced plus 50% more seed and the sub-plots sown with untreated seed (Table 7.4). The density of *D. eriantha* increased for all treatments, except for the sub-plots sown with enhanced plus 50% more seed. The density of *C. gayana* decreased throughout the two years in all the plots because it is a short lived perennial grass. The density of *C. ciliaris* and *P. maximum* increased for all the treatments except for the 50% more enhanced seed treatment. The density of *Cynodon dactylon* increased in the sub-plots sown with untreated (35 to 61 plants/m², Table 7.4) and enhanced seed (27 to 75 plants/m², Table 7.4). The density of *C. dactylon* decreased in the control plot (199 to 162 plants/m²) and sub-plots sown with 50% more enhanced seed (31 to 30 plants/m²). The density of *Aristida congesta* increased only for the sub-plots sown with the enhanced seeds and did not occur in the control plot. The density of *Chloris virgata*, *Brachiaria serrata*, *Urochloa panicoides* and *Aristida diffusa* increased throughout all the treatments. The density of *Setaria sphacelata* decreased in both of the enhanced treatments.

The density of *Brachiaria serrata* decreased in the plots sown with 50% more enhanced seed treatment, but increased in the control plot. The density of *Cymbopogon plurinodis* (narrow-leafed turpentine grass) increased only in the control plot. The density of *Bothriochloa insculpta* increased in the enhanced treatment and in the control plot. The densities of *E. rigidior* and *E. lehmanniana* decreased in the sub-plots sown with enhanced seed.

Table 7.3: The change in frequency (%) of the dominant grass species sown in plots (e- enhanced seed, e50 – enhanced plus 50% more seed and untreated seed) and the control plot (no oversowing, only rip plough cultivation) from the 1996/1997 to 1998/1999 seasons. The numbers in brackets are the values for the plots sown with 50% more seed

	Enhanced seed						Untreated seed			Control inside enclosure		
	96/97		97/98		98/99		96/97	97/98	98/99	96/97	97/98	98/99
	e	e50	e	e50	e	e50						
<i>Aristida congesta</i>	0	3	0	2	0	12	0	1	4.3	6	1.5	12
<i>Aristida diffusa</i>	0	0	0	3	0	0	-	-	-	-	-	-
Bare ground	0	0	0	2.2	0	0	0	6	0	0	20.3	0
<i>Botriochloa insculpta</i>	-	-	-	-	-	-	-	-	-	0	0	3
<i>Brachiaria eruciformis</i>	1	10	0	0	0	0	10	0	0	6.8	0	0
<i>Brachiaria serrata</i>	0	0	0	0	0	1	-	-	-	-	-	-
<i>Cenchrus ciliaris</i>	1	1	1	3	2	2	6	6	3.8	0	0	0
<i>Chloris gayana</i>	0	1	1	2	0	6	3	13	9.1	0	0	0
<i>Chloris virgata</i>	37	30	0	0	31	24	35	0	22	61.2	0	41
<i>Cynodon dactylon</i>	8	14	50	45	17	27	21	51	28	13.6	68.9	17
<i>Digitaria eriantha</i>	5	11	12	27	3	14	14	22	24	0	0	12
<i>Eragrostis curvula</i>	0	0	0	0	-	1	-	-	-	-	-	-
<i>Eragrostis lehmanniana</i>	5	-	3	-	12	-	0	1	0.8	0	0	0
<i>Eragrostis rigidior</i>	27	0	17	0	15	0	1	4	1.1	0	0	2
<i>Panicum maximum</i>	6	9	7	14	8	5	6	8	15	0	0	1
<i>Setaria nigrirostris</i>	0	0	0	3	2	3	0	6	4.4	0	9.3	8
<i>Tragus berteronianus</i>	0	3	-	0	0	0	-	-	-	-	-	-
<i>Urochloa mosambicensis</i>	18	10	0	1	4	3	8	1	7.1	8.2	0	5

Table 7.4: The change in density (plants/m²) of the dominant grass species at Kromsprit during the study period 1996 -1998. Species with a density of less than one plant/m² were not tabled, unless it is a sown-in species. In the table enhanced seed are indicated by e and enhanced plus 50% more seed by e50

	Enhanced seed (plants/m ²)				Untreated seed (plants/m ²)		Control inside enclosure	
	96/97		97/98		96/97	97/98	96/97	97/98
	e	e50	e	e50				
<i>Aristida congesta</i>	1	4	3	0	1	0.1		
<i>Aristida junciformis</i>	0	0	2	4	0	1.8	0	24
<i>Botriochloa insculpta</i>	0		2.3				0	9
<i>Brachiaria serrata</i>	0	0	1	5.5	0	9.3	0	25
<i>Cenchrus ciliaris</i>	0	1.9	1	1.5	0.9	2	0	0
<i>Chloris gayana</i>	0	1.3	0	0.7	6.1	2.6	0	0
<i>Chloris virgata</i>	0	0	27	42	0	28.5	0	117
<i>Cymbopogon plurinodis</i>	0		0		0	0	0	1
<i>Cynodon dactylon</i>	27	31	75	30	34.8	60.7	199	162
<i>Digitaria eriantha</i>	3	6.5	5	3.9	3.2	5.5	0	18
<i>Eragrostis curvula</i>	0		1					
<i>Eragrostis lehmanniana</i>	1.9		0.1					
<i>Eragrostis rigidior</i>	3.2		2.6					
<i>Panicum maximum</i>	0	0.5	1	0.2	0.4	0.8	0	0
<i>Setaria nigrirostris</i>	2	0.6	0	0			1	1
<i>Setaria sphacelata</i>	0		6.2					
<i>Urochloa mosambicensis</i>	0	1.1	0	0			0	10
<i>Urochloa panicoides</i>	0	-	3.4		0	5.2	0	12

The density of *E. curvula* and *Setaria sphacelata* (common bristle grass) increased in the enhanced plots. *C. dactylon* is more frequent in all the treatments but had less plants/m² than in the control plots. *C. dactylon* and *C. virgata* (indicator species of disturbance, Van Oudtshoorn, 1999) occurred at extremely high densities in the control plot alone, indicating that the rip plough cultivation method combined with

the oversowing treatment effectively controlled these two species of poor ecological value.

7.4.6 Trajectories over time

Ordination analysis techniques place trajectories on a gradient, expressing the change in vegetation composition over time. All the sample plots, represented by the different sub-plots with different seed mixture treatments were ordinated using the DCA-ordination procedure of the DECORANA program (Hill, 1979) ordination module in the ISPD computer package (Bosch, *et al.*, 1992).

The change in species composition from 1996 to 1998 is explained on ordination axes 1 and 2 of the DCA-ordination carried out on the total data set. *C. dactylon* and *C. virgata* were identified as species that greatly influenced the ordination, especially towards the control plot (see Table 7.4). The results clearly show that two grass communities developed after the restoration treatment from a *C. virgata* dominant community (on the right of ordination axis 1) to *E. lehmanniana* and *D. eriantha* dominated communities arising from the untreated seed on the left of ordination axis 1 (Fig. 7.15) after three years. The control plot where no restoration treatment was done (plot 43) was mainly characterised by bare ground and showed very little change in the three year period.

The restoration treatment was highly beneficial for the establishment of perennial climax grass species replacing the annual grass species. The ordination results are in accordance with the frequency (Table 7.3) and density data (Table 7.4).

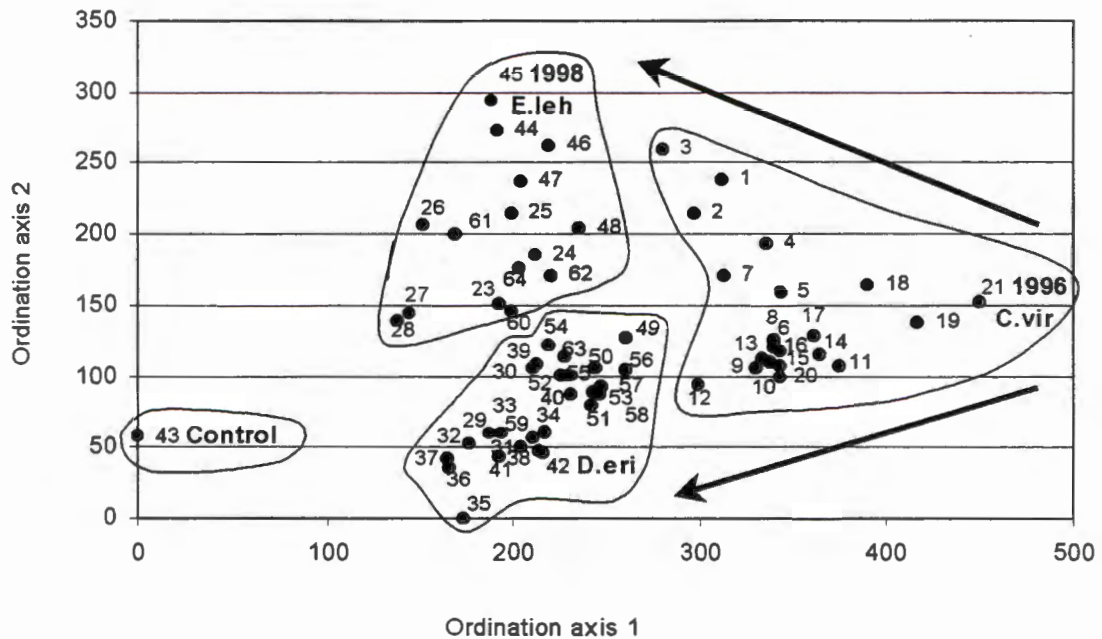


Figure 7.16: Results of a DCA ordination to show the change in dominant grass species at Kromspruit from a *Chloris virgata* plant community (plots 18 – 21) in 1996 to *Digitaria eriantha* (plots 35 – 49) and *Eragrostis lehmanniana* (plots 44 – 47) plant communities (axis 1) in 1998. The control plot is also shown.

7.5 Discussion and conclusions

Although the untreated seed had the highest germination rate per number of seed in the laboratory in comparison to the enhanced seed (Fig. 7.3), the enhanced seed had the highest seedling survival in the field (Fig. 7.6) supporting findings by Tainton (1981), Siebert Seed Consultants¹⁰ and Advance Seed Co. (Pty) Ltd⁷. Of the three treatments (enhanced, enhanced plus 50% more seed and untreated seed) the enhanced plus 50% more seed had the highest seedling survival percentage. For a land manager left with the choice of these three options, enhanced plus 50%

¹⁰ ☒ Siebert Seed Consultants, Nieuwestraat 58, Potchefstroom, 2531, ☎ 083 300 6938.

more seed is the better choice, being more economical on the long run (see Section 2.7, Chapter 2).

Specific plant species are adapted to grow together in specific habitats. Furthermore, different species growing together suggest the development or utilization of different niches within the same habitat (Begon, *et al.*, 1990). The success of such niche utilization would be reflected in the population structure. This study supports the specific habitat and niche theory. Thus, a specific grass mixture is suitable for the black vertic clay overlain with yellow-red sand, having a sandy-clay-loam texture, a pH of 7 to 8 and a rainfall of 570 mm/yr. for this particular study area. This grass mixture would be the one in which all the constituent species grew together (Fig.7.6 and 7.7). Another aspect to consider is the presence of all three growth stages as an indication of a sustainable population (Fig. 7.13). *D. eriantha* is a species that persisted in the sub-plots throughout the study period and together with *C. ciliaris* and *P. maximum* of the sub-plots sown with enhanced plus 50% more seed are advised for restoration purposes in similar environments, because they are the only species complying with the above-mentioned criteria.

The frequency and density of the sown-in species would decrease or increase as a reaction to various factors including management, environment and species adaptability. This clay soil has shrinking and swelling characteristics that are influenced by rainfall, and unless seed is sown when rip plough cultivation is applied, few pasture species will establish (in accordance with Davies, *et al.*, 1986). Qualitatively, the fencing of the study area increased the perennial species. The process of succession is faster, however, than that found in studies like Allen, *et al.* (1995) and Dzwonko & Loster (1998). In agreement with Snyman & Fouche (1991), the frequency and density of the grass species are closely related to the rainfall patterns of the area. An increase in rainfall therefore led to an increase in the frequency and density of the species. Other species stimulated by the rip plough cultivation method and which could be considered for pasture restoration was *E. lehmaniana* and *B. insculpta*.

At the time of survey, the average short-term rainfall was lower than the average long-term rainfall for that month (Fig. 7.2). The average short-term rainfall for February 1997 (49mm/month) was below the average long-term rainfall for

February (98mm/month). Also, the average short-term rainfall for March 1999 was lower than the average long-term rainfall for March (50 years prior to study). In agreement with Milton (1994) mortality of seedlings appeared drought induced. In 1997 most of the sown-in species showed low frequency values (Table 7.3), corresponding with the low rainfall in February (48 mm/month, Fig. 7.2). A peak of rainfall occurred in March 1997. In 1998, the rainfall was approximately 50% more in February (1998) than in the previous year and the larger amount of rainfall was also reflected in the higher frequency values in 1998 (Table 7.3), except for *C. ciliaris* of the untreated seed. The rest of 1998 and 1999 had rainfall below the average long-term rainfall of the area. Only the months February and May 1999 had rainfall above the average long-term rainfall for the two months. The frequencies of *D. eriantha* (of the enhanced seed), *C. gayana*, and *C. ciliaris* (of the untreated seed) decreased with the decrease in rainfall in 1999. *P. maximum*, *D. eriantha* (of the untreated seed) and *C. ciliaris* (of the enhanced seed) increased in 1999, regardless of the decrease in rainfall. The reason for the increase in density is not clear, both the enhanced and the untreated seed were subject to the same amount of rainfall and competition.

Apart from the oversown seed, the soil seed bank is atypical of the standing vegetation, supporting Bakker, *et al.* (1996). Soil seed banks atypical of the standing vegetation usually represent previous vegetations. The seed of the sown-in species did occur in the soil seed bank three years after the restoration application, proving that the established populations attributed to a future generation by adding seed to the soil seed bank.

Rip ploughing and oversowing combined with fencing not only aided the typical succession process but also accelerated it. The barbwire single strand fencing withheld large herbivore grazing, effectively providing a camp system that allowed the grass population freedom from excessive grazing pressure. The oversown grass species, as well as other perennial grasses, were able to establish large tufts of biomass without the defoliation that often stunt a seedling in open pasture. According to the ordination, annual composition dominated by *C. virgata* was transformed to a perennial grass composition within a matter of three years with the provision that adequate rainfall occurs. The tempo of this succession is contrary to the common 20 yrs. plus for succession of this nature to take place (Barbour, *et*

al., 1987), but according to Tainton (1981) and Van der Merwe (1997) similar results were obtained where similar strategies were applied.

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Chapter 8. The sustainability of certain grass species in a restored pasture (communal area Davidkatnagel)

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8.1 Abstract

Degradation in the Davidskatnagel study area involved bare patches and the occurrence of mostly annual species of low ecological status. The soil was rip ploughed. Different mixtures of treated (enhanced) and untreated caryopses (seed) of *Digitaria eriantha*, *Chloris gayana*, *Cenchrus ciliaris* and *Panicum maximum* were oversown into part of the degraded area. Sampling included the frequency of species, describing the vegetation composition and condition. Density data of the seedlings, vegetative and reproductive growth stages were used to determine the sustainability of the oversown grass mixtures. The soil seedbank was also analysed to determine the availability of species therein and to see whether the oversown species occurred in the soil seedbank. Frequency and density decreased during 1995-1999, except for *D. eriantha* and *C. ciliaris*. The soil seed bank analysis corresponded with current literature and contained seed of *P. maximum* and *C. gayana*. The rip plough cultivation method negatively influenced *Sporobolus africanus* and other annual grass species, but benefited species such as *Eragrostis rigidior*. A succession gradient exists on the first axis of the ordination, with the vegetation composition changing from *C. gayana* – *P. maximum* dominated in 1997 to a *D. eriantha* dominated vegetation community in 1999. The grass species number increased by ten species to 23. The untreated seed had the highest germination rate in the laboratory, but the natural field seedling survival rate of the enhanced seed was the highest. From the results of this experiment it is evident that the suitable grass mixture for this clayey soil type is *D. eriantha* and *P. maximum* of the enhanced seed type. *P. maximum*, though, is expected to decrease over the long-term. Untreated seed of *C. ciliaris* is also suited for restoring this area. The conclusion is that natural succession in degraded areas can be accelerated by the rip plough cultivation method and oversowing of perennial climax grass mixtures, using enhanced seed of specific species.

Additional index words: degraded rangeland, denuded soil, *Chloris virgata*, rip ploughing, species richness

8.2 Introduction

The degradation process of vegetation (see Section 1.1) in the semi-arid grasslands of southern Africa is characterized by changes in the ratio between palatable and unpalatable species caused by high grazing pressure and erratic rainfall (Milton & Dean, 1995, Behnke & Abel, 1996; Brunson & Steel, 1996, Hoffman *et al.*, 1999). This is also the case in the Davidskatnagel rural area.

Public concern about the natural environment, its management and its influence on the local economy has increased (Cohen, 1997). The land users living in rural areas themselves do not, however, perceive degradation as the primary problem (Hoffman *et al.*, 1999). One school of thought concerned with degradation, states that traditional agro-ecosystems are still in use and show strong evidence for a socio-ecological stability that modern, mechanized systems can envy (Haro *et al.*, 1996). An agro-ecosystem that continues to be productive for a long period of time without degrading its resource base – either locally or elsewhere - can be said to be sustainable (Gliessman, 1998). Whichever paradigm lies behind a restoration action, the strategy aims at sustainable use of the communal land (De Lange, 1995).

Even if the species composition of an area appears unchanged on the surface, grass populations have high turnover rates. State and transition and vegetation dynamic models (Bosch, 1989, Westoby *et al.*, 1989, Bosch & Kellner, 1991) describe these changes and estimate the thresholds between different states (Milton & Hoffman, 1994, Meyer & Schmid, 1999). The extent of degradation varies between different states. Often a degraded area cannot return to a previous state through normal management strategies and succession processes. Such an area is said to have crossed the threshold of that specific state (Bosch & Kellner, 1991). Restoration technologies such as the rip plough cultivation method (Davies *et al.*, 1986) and the oversowing of perennial grasses (Tainton, 1999) can overcome these thresholds. As the main aim of this study, the establishment and development of grass populations derived from different restoration technologies, including cultivation and oversowing treatments, are tested at Davidskatnagel, a communal managed area in the rural parts of South Africa. The main aim is subdivided into:

- 1) to determine the seed germination rate of enhanced and untreated seed and comparing it to seedling survival in the field;
- 2) to identify a suitable grass mixture for restoration purposes in these areas;

- 3) to use frequency and density data consisting of growth stage data to describe the development of the grass populations over a period of four years;
- 4) to compare these data to data from a soil seed bank analysis and
- 5) to determine the change in overall species richness.

8.3 Materials and methods

8.3.1 Study area

The study site is situated near the rural settlement of Davidskatnagel (26°30'E, 25°22'S, Fig. 8.2) near Madikwe in the North West Province (South Africa). This rural community is situated in the Savanna Biome (Rutherford & Westfall, 1994) and is part of the Bankenveld Veld Type (Acocks, 1988) with a typical Clay Thorn Bushveld (Bredenkamp & Van Rooyen, 1996).

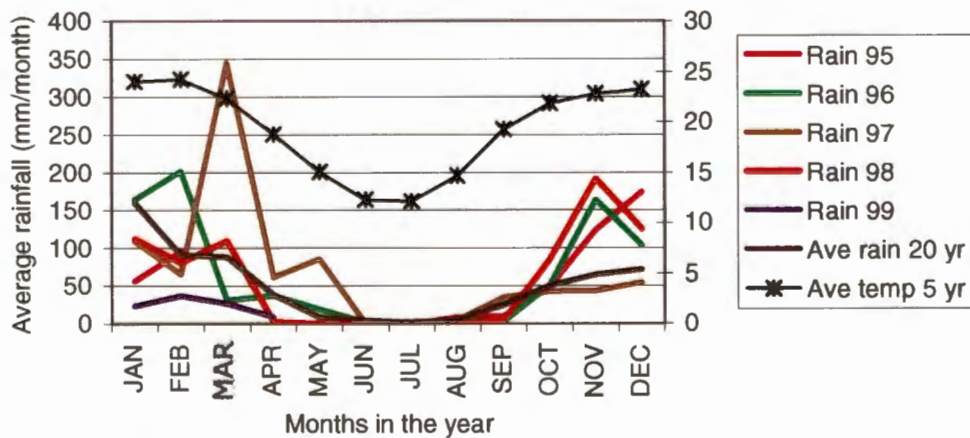
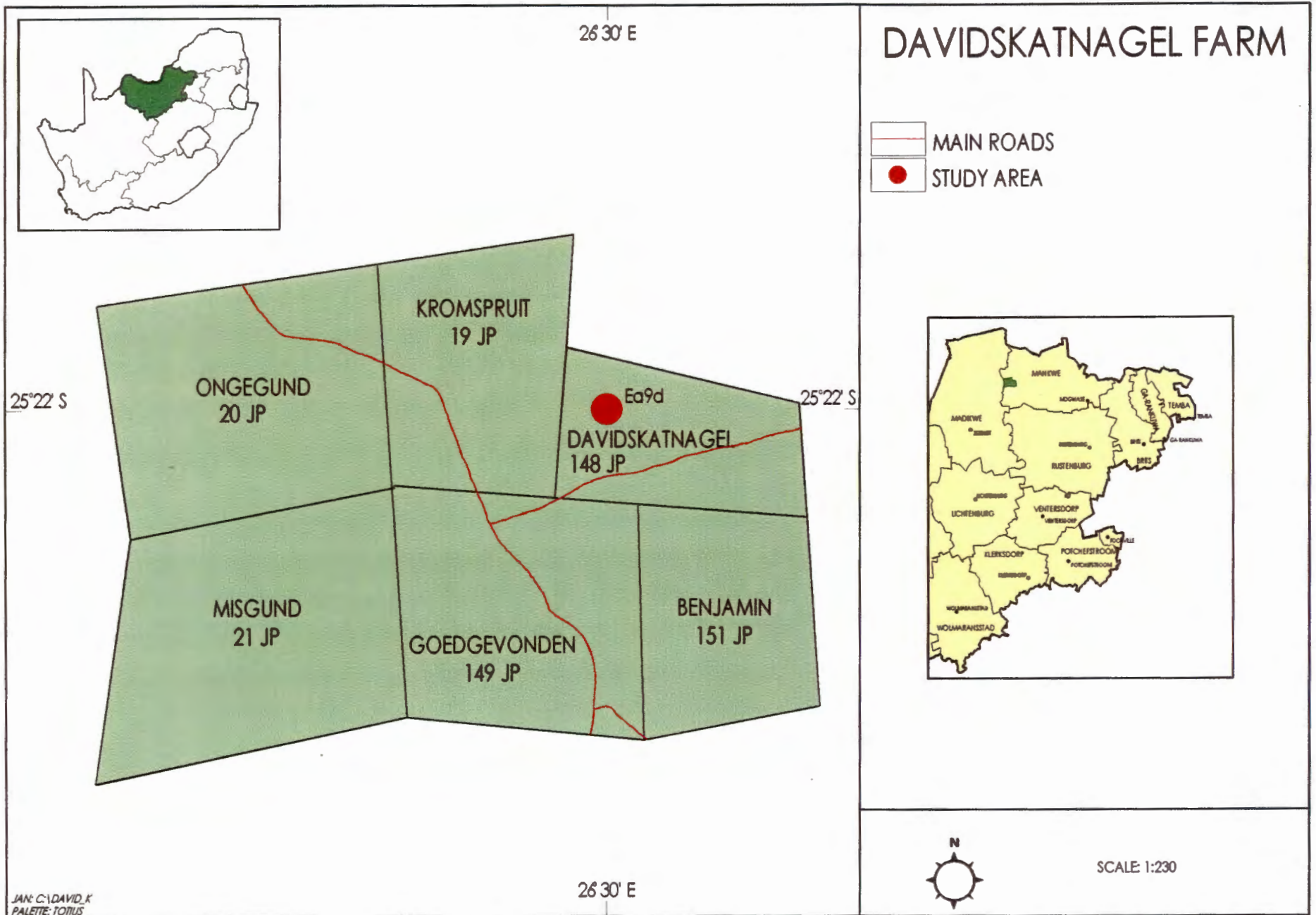


Figure 8.1: The average long-term (20 yrs.) and short-term (1995-1999) rainfall and temperature (°C) for the Davidskatnagel study area.

Annual grasses of poor fodder quality characterize the grassy layer, such as *Urochloa panicoides* (garden urochloa) and *Tragus berteronianus* (carrot-seed grass) (Van Oudtshoorn, 1999). The average long-term rainfall of the area is 577 mm per year and the average short-term rainfall for the study period 1994-1997 was 310 mm per year (AgroMet³)(Fig. 8.1).

³ AgroMet Potchefstroom, Institute for Soil, Climate and Water, P/b X 1251, Potchefstroom, 2520

Figure 8.2: The location of the study area near the Davidskatnagel rural community (supplied by Dept. of Geography and Environmental Study: Cartographic and GIS Services)



Rainfall above the long-term average occurred in November and December 1995, February, November and December 1996, March, April and May 1997, and October, November and December 1998. A marked rainfall peak occurred in March 1997. The minimum temperature between 1995 and 1999 was -5°C . The maximum temperature between 1995 and 1999 was 38.1°C . The long-term average temperature is depicted in Figure 8.1. The soil is black vertic clay (Bredenkamp *et al.*, 1996), has a sandy-clay-loam texture and a 29% clay content. The pH of the soil is 7. The topographical unit is characterized by flat footslopes (Land Type Survey Staff, 1984a).

8.3.2 Restoration treatment

The restoration process for this area entailed a rip plough cultivation method (Tainton, 1981, Van der Merwe, 1997) to a depth of 150 mm with rip rows 800 mm apart. Seed of the climax grass species (native to the area) were oversown by hand into the furrows and slightly covered with soil. The grass species used were *D. eriantha*, *P. maximum*, *C. ciliaris* and *C. gayana*. The total area treated in this way occupied 0.05ha, which was divided into a total of 11 subplots with one serving as a control. The trial area was fenced, excluding all grazing, for four years (1996 to 1999). The size of each sub-plot was 100 m x 5 m. A control plot outside the enclosure was grazed.

The 10 sub-plots were divided into five sub-plots oversown with enhanced seed (Table 8.1, sub-plots 1-5) and five with untreated seed (Table 8.1, sub-plots 6-10). Grass seed mixtures (Table 8.1) were oversown into each sub-plot in a 1 (untreated seed): 1.5 (enhanced seed) ratio. The enhanced seed is heavier than the untreated seed and had less seed per kilogram so that 50% more of the enhanced seed was oversown in sub-plots 1 to 5.

Table 8.1: The average weight (in kilograms/hectare) of seed (no. of seed/g in brackets) oversown in the different sub-plots at the Davidskatnagel study area, North West Province, South Africa. Abbreviations for the species are used throughout the chapter

Species	Treatment	Sub-plot 1 kg/ha (no. of seed per gram)	Sub-plot 2 kg/ha (no. of seed per gram)	Sub-plot 3 kg/ha (no. of seed per gram)	Sub-plot 4 kg/ha (no. of seed per gram)	Sub-plot 5 kg/ha (no. of seed per gram)
<i>Digitaria eriantha</i> (D. eri)	Enhanced	1 (981)	2.3		2.3	
<i>Panicum maximum</i> (P. max)	Enhanced	1 (546)	2.3	2.3		1.5
<i>Cenchrus ciliaris</i> (C. cil)	Enhanced	1.9 (105)		3.8		2.5
<i>Chloris gayana</i> (C. gay)	Enhanced	1 (646)			2.7	1.5
		Sub-plot 6	Sub-plot 7	Sub-plot 8	Sub-plot 9	Sub-plot 10
D. eri	Untreated	0.8 (2655)	1.5		1.5	
P. max	Untreated	0.8 (1994)	1.5	1.5		1
C. cil	Untreated	1.3 (399)		2.5		1.7
C. gay	Untreated	0.8 (3778)			1.5	1

8.3.3 Field sampling methods

Vegetation surveys were carried out during February/March in the late growing and summer seasons of 1996-1999. In each sub-plot, the frequency of the grass species was determined with the wheelpoint method, which records the nearest plant in the rip rows (Tidmarsh & Havenga, 1955). For each sub-plot, a total of approximately 100 points were recorded. A quadrat (1 x 1 m) was used to determine the vegetation density. Three different plant growth stages were noted. Established seedlings and/or tillers (a plant with one shoot protruding from the ground as in the case of *Cynodon dactylon* (Bermuda grass), vegetative mature plants (having more than one shoot protruding from the ground) and reproductive plants (clearly bearing reproductive organs or the remains of it) were counted.

The second year's (1997/1998) number of surviving seedlings were used for the calculations and were compared to the first year's (1996/1997) number of seeds oversown and the germination rate in the laboratory of the seed. The presence of

all three growth stages in this study was taken as an indication of a healthy, sustainable grass population.

8.3.4 Soil seed bank analysis

Soil samples were collected for the soil seed bank analysis in the summer period of 1998/1999. Three soil samples per grid were collected with a soil auger (approximately 1006 cm³, Du Toit & Alard, 1995) and allowed to air dry for two weeks. The three samples of each sub-plot were combined (approximately 3017 cm³) in a 300 mm x 200 mm x 80 mm (4800 cm³) seed tray. Soil samples greater than 100 cm³ soil sample in each 1 x 1 m plot (Tsuyuzaki & Kanda, 1996) were used in the study. Seed germination rate was determined by germination (Tsuyuzaki & Kanda, 1996). The analysis proceeded in a greenhouse with a day temperature of 28 °C day and a night temperature of 20 °C. The soil was kept moist (Du Toit & Alard, 1995; Schrautzer *et al.*, 1996). The species were allowed to germinate (first appearance of the radicle and the plumula, Weinbrenn, 1946) and left until identification was possible. Were two or more of the same species germinated, all but one specimen were removed to reduce seedling competition. Identified species were also removed. The results of the soil seedbank analysis were noted and compared to the standing grasses of the study area. A period of 150 days is sufficient for only 2% of seed to remain in the soil (O'Connor & Everson, 1998).

Seedling density of the soil seedbank analysis per 1 x 1 m x 0.02 m was calculated as follows:

Three samples of >1006 cm³ soil were combined to 4800 cm³ (amount of soil fitted into 300 mm x 200 mm x 80 mm containers). That is converted to 1 x 1 m x 0.02 m, as a measurement of the seedling density per square meter in the field.

For example, 46 seedlings germinated from a seed tray. Converting the number of seedlings/cm³ to the number of seedlings/1 x 1 m x 0.02 m (20 000 cm³ is the conversion factor):

$$\frac{46 \text{ seedlings}}{4800 \text{ cm}^3} \times \frac{20\,000 \text{ cm}^3}{4800 \text{ cm}^3}$$

or $\frac{46 \text{ seedlings}}{0.0048 \text{ m}^3} \times 0.02 \text{ m}^3$

$$= 191.7 \text{ seedlings} \cdot 0.02 \text{ m}^3$$

or 191.7 seedlings/1 x 1 x 0.02 m.....8.1

8.3.5 Germination tests

The germination rate of the seed batches used in the field experiment was tested in the laboratory to establish their germination rates under optimal conditions. Ten seeds per species were placed in containers, 10 ml of distilled water was added to each, and the containers were sealed to avoid moisture loss (see Section 9.11, Chapter 9). The trials were carried out at 25 °C for 28 days in a Gallenkamp Plus II incubator (Monitoring and Control Laboratories⁶). The number of seed that germinated was noted as the germination rates of the given grass species.

8.3.6 Data analysis

Averages of the frequency and density data of the grass species in the restored sub-plots were calculated in the following manner:

For a given weight of seed was oversown per hectare (without the adjustments required for the mixing of different seed) impurity values were subtracted from the specific weight, resulting in the weight of the seed that will potentially germinate (according to ISTA procedures). The number of seed per gram oversown into the sub-plots was compared to the number of seed oversown and the number of plants surviving after the first season. The Spearman rank order correlation method was also used (Steyn *et al.*, 1995).

The quantitative data was statistically analyzed using the ANOVA/MANOVA technique in the STATISTICA for Windows (StatSoft, Inc., 1999) computer program. The purpose was to find significant differences between the means of a variable by comparing that variable's variances. Results were considered statistically significant if $p < 0.05$ except where otherwise indicated.

⁶ ☒ Monitoring and Control Laboratories (Pty) Ltd. Box 890226, Lyndhurst 2106, ☎ + 27 11 483 3149 (o), + 27 11 483 2146 (f).

Using multivariate analysis techniques, such as DECORANA (Hill, 1979) the change of species' composition over time was determined by trajectories on a gradient. DCA ordination was used for the gradient analysis conducted in the Integrated System for Plant Dynamics computer program (Bosch *et al.*, 1992).

8.4 Results

8.4.1 Seed germination rate, seedling survival and grass mixtures

The nonparametric distribution of the data necessitates the use of statistical methods such as the analysis of variance (Table 8.2.). The variance for the number of seed oversown into the sub-plots compared with the laboratory germination rate and the field seedling survival is due to the statistical program's incapability to deal with values greater than 30 000. Unfortunately, the information regarding the capacity of the program was discovered at the point were all the calculations were done and the dissertation nearly finished.

Table 8.2: Descriptive statistics of the number of seed oversown into the sub-plots, the number of the seedling, vegetative and reproductive plants as well as the frequency and density data for Davidskatnagel

	Mean	Variance	SD	Error
Frequency	2.77	48	6.95	0.39
Density	0.34	2	1.35	0.08
No. of seedling, vegetative and reproductive	78	2035	45.11	2.54

The number of seed oversown into a sub-plot of 350 m² was between 9 975 and 143 464. This also suggests that the statistical analysis poorly described the data of the number of seed oversown into the sub-plots. The variances of the other values are low and the analysis thus describes that data better.

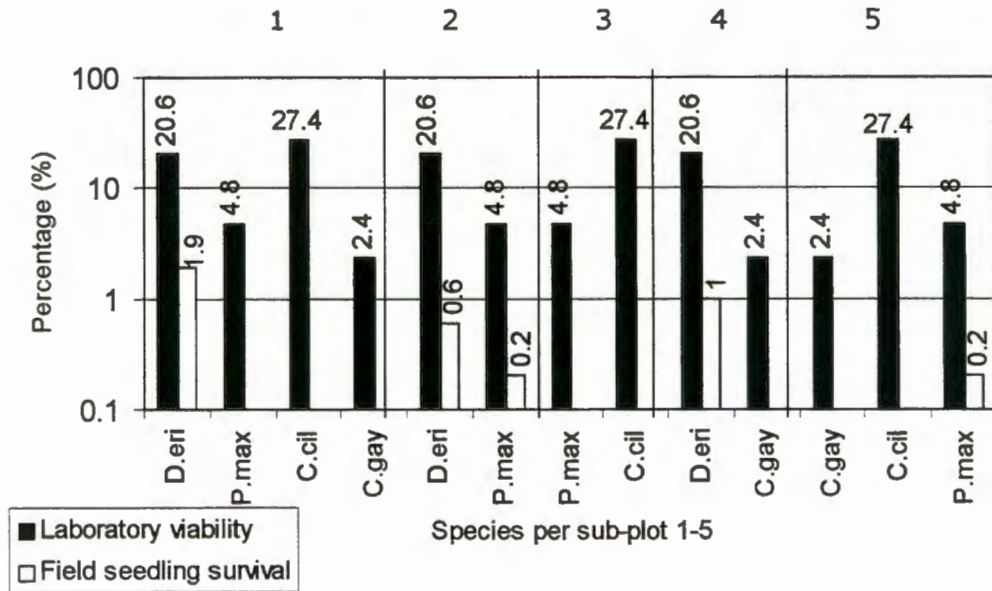


Figure 8.3: The restoration treatment where enhanced seed was used at Davidskatnagel: a comparison of the germination rate of the seed in the laboratory to the percentage of seedlings that survived in sub-plots 1-5 in the field (Table 8.1).

Figures 8.3 and 8.4 compares the percentage of individuals (seed) that germinated in the laboratory to the percentage of seedlings that survived in the field for the enhanced plus 50% more seed and the untreated seed.

The untreated seed of sub-plot 6 (Fig. 8.4, sub-plot 6) had the highest germination rate in the laboratory (48%). Of these *C. ciliaris* had the highest germination rate (48%, Fig. 8.4.), followed by *C. gayana* (39%, Fig. 8.4), *D. eriantha* (24%) and then *P. maximum* (12%). A Spearman rank order correlation detected that each treatment (enhanced and untreated seed) had a specific laboratory germination rate (Spearman $R = 0.87$). No marked correlation exists for any of the field seedling comparisons of sub-plots 1 and 6, suggesting that there is a significant difference between the enhanced and untreated seed. Enhanced seed of *D. eriantha* had a higher seedling survival (2%, Fig. 8.3) than the untreated seed of *D. eriantha* (1%, Fig. 8.4) under natural conditions in the field. In sub-plot 6 oversown with untreated seed, only two of the constituent species (*D. eriantha* and *P. maximum*) survived.

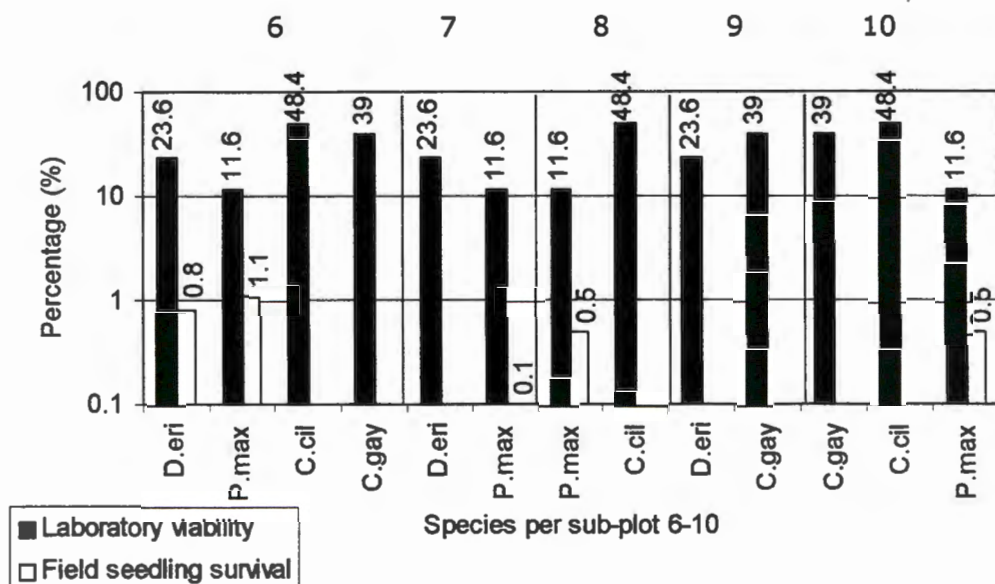


Figure 8.4: The restoration treatment where untreated seed was used at Davidskatnagel: a comparison of the germination rate of the seed in the laboratory to the percentage of seedlings that survived in sub-plots 6-10 in the field (Table 8.1).

There is no marked correlation for sub-plots 2 and 7 (Fig. 8.3 and 8.4) oversown with a mixture of the enhanced and untreated seed of *D. eriantha* and *P. maximum*, suggesting that the enhanced and untreated seed differs significantly ($p = 0.02$, Table 8.3). The untreated seed had a higher germination rate in the laboratory (48.4%, Fig. 8.4, sub-plot 7). *D. eriantha* (untreated) had the highest germination rate of the species of these sub-plots (24%, Fig. 8.4, sub-plot 7). The *D. eriantha* and *P. maximum* population from the enhanced seed had the highest seedling survival (1 and 0.2%, respectively, Fig. 8.3, sub-plot 2).

None of the species oversown in sub-plot 3 had seedlings surviving in the field (Fig. 8.3). There is no marked correlation between the sub-plots oversown with enhanced and untreated seed. The untreated seed of *C. ciliaris* had the higher germination rate in the laboratory (48%, Fig. 8.4. versus 27%, Fig. 8.3, sub-plots 3 and 8). The untreated seed of *P. maximum* was the only seed that produced seedlings in this sub-plot.

There is no marked correlation for sub-plots 4 and 9 oversown with the enhanced and untreated seed (Fig. 8.3 and 8.4). The untreated seed of *C. gayana* had the higher germination rate in the laboratory (39%, Fig 8.4 versus 21%, Fig. 8.3, sub-plots 4 and 9) with *C. gayana* germinating the most in the sub-plot with untreated seed (39%, Fig. 8.4, sub-plot 9) and *D. eriantha* germinating most in the sub-plot oversown with enhanced seed (21%, Fig. 8.3). The untreated seed of both species did not survive in the field, but enhanced *D. eriantha* survived into the second year (1%, Fig 8.3, sub-plot 4).

The enhanced and untreated seed in sub-plots 5 and 10 had a marked correlation for their germination rates in the laboratory ($R = 0.88$). Once again, the untreated seed of *C. ciliaris* had the higher germination rate in the laboratory (48%, Fig. 8.4 versus 27.4%, Fig. 8.3, sub-plots 5 and 10), with *C. gayana* the best of the three species in these sub-plots (39%, Fig. 8.4, sub-plot 10). A marked correlation exists for the species and the survival of their seedlings in the field ($R = -0.85$). Only *P. maximum* seedlings survived in the field. Most seedlings originated from the untreated seed (1%, Fig. 8.4 versus 0.2%, Fig. 8.3, sub-plots 5 and 10).

8.4.2 Frequencies

Oversown species

None of the oversown species occurred in the study area at the time of restoration. The average frequencies of the oversown species increased from, for example, 0% to 34% over the four years for *D. eriantha* in the sub-plots where enhanced seed had been used (Fig 8.5, *D. eri e*). However, where the untreated seed was used, the population decreased (10% to 17% to 9%). *P. maximum* established from enhanced seed decreased (15% to 7%). The untreated *P. maximum* first decreased and then stabilized in the fourth year (27% to 9%). *C. ciliaris* (enhanced: 14% to 8%; untreated: 5% to 1%) and *C. gayana* (enhanced: 8% to 5%; untreated: 14% to 1% to 4%) decreased. *C. ciliaris* and *C. gayana* increased in the fourth year in the sub-plots oversown with untreated seed.

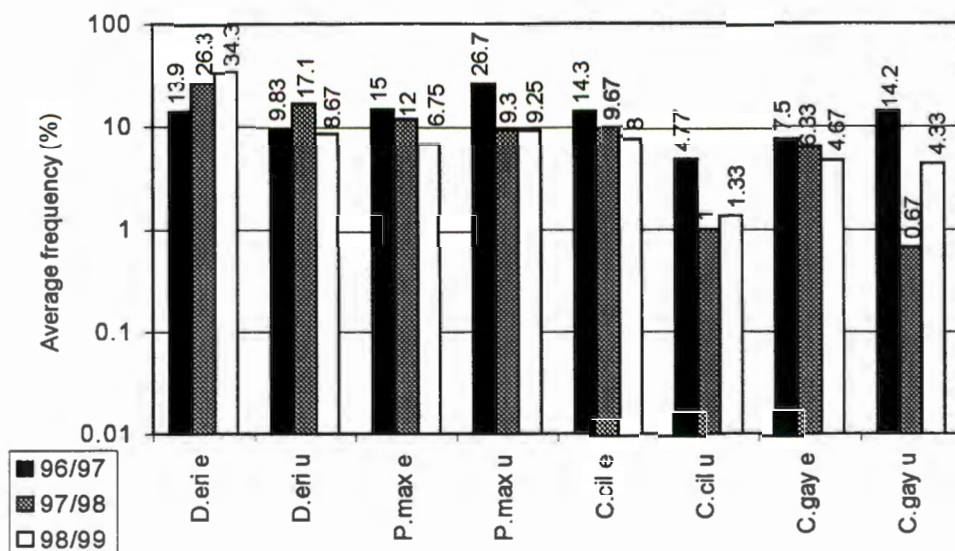


Figure 8.5: The average frequency of oversown grass species over a three year period, enhanced (e) and untreated (u) seed oversown at Davidskatnagel in a rip furrow 150 mm deep. Abbreviations are according to Table 8.1.

8.4.3 Density

The density of *D. eriantha* (enhanced seed) (3% to 3%, Fig. 8.6, D.eri e) and *C. gayana* (0 plants/m² to 3 plants/m², Fig. 8.6, C.gay e) increased from 1997-1999. *C. ciliaris* from the untreated seed also increased (1 plants/m² to 2 plants/m², Fig. 8.6, C.cil u). The density of untreated *D. eriantha* was stable over the last two years of the study (8 plants/m² to 7 plants/m², Fig. 8.6, D.eri u). *P. maximum* from both the enhanced and untreated seed decreased between 1997 and 1999 (4 plants/m² to 1 plants/m²; P.max e; 1 plants/m² to 1 plants/m², P.max u, Fig. 8.6). *C. ciliaris* from the enhanced seed decreased (1 plants/m² to 0 plants/m², C.cil e, Fig. 8.6). *C. gayana* from the untreated seed (C.gay u, Fig. 8.6) did not increase in the last two years of the study due to the grass being a short-lived perennial grass.

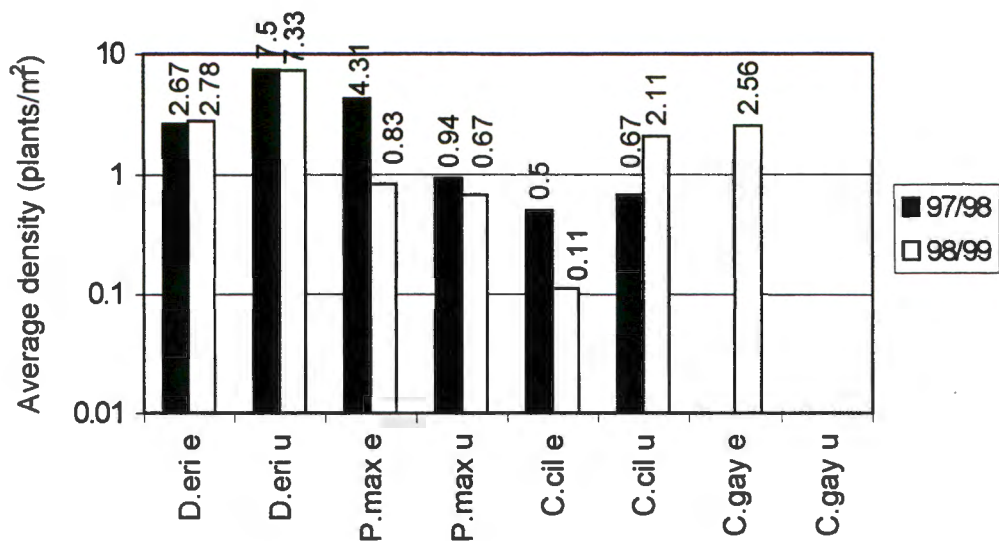


Figure 8.6: The average density (plants/m²) of oversown grass species over a four year period, enhanced (e) and untreated (u) seed oversown in a rip furrow 150 mm deep (p = 0.02). Abbreviations are according to Table 8.1.

8.4.4 Growth stages

The growth stage data (seedling, vegetative and reproductive plant numbers per square meter) is from surveys taken in the year 1997/1998, two years after the restoration application in 1995. The grass populations arising from enhanced seed that formed sustainable populations are *D. eriantha* and *P. maximum*, as they have representatives of all three growth stages, namely seedlings, vegetative and reproductive growth stages. (Note, the reference is to the sustainability of the grass populations and not the sustainability of the area). The focus of the growth stage analysis is not so much on decline or increase as on the representation of the species in all three growth stages and their subsequent contribution to the population growth of the following season.

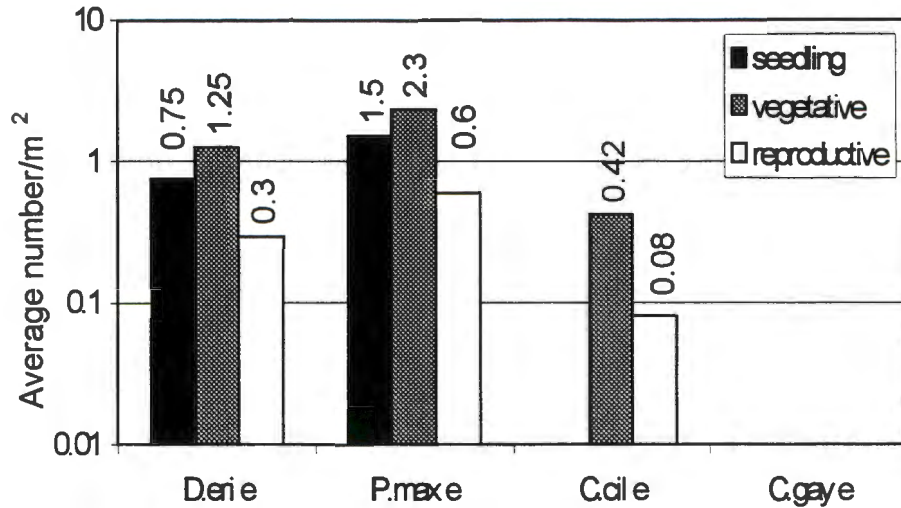


Figure 8.7: The average number of individual plants of each growth stage of the species from the enhanced seed oversown at Davidskatnagel.

P. maximum from the enhanced seed had the highest numbers for each growth stage (2 seedlings/m², 2 vegetative plants/m² and 1 reproductive plants/m²). The frequency of *C. ciliaris* and *C. gayana* from the enhanced seed increased, but the species did not form sustainable populations until 1998. It seems that *C. ciliaris* is not adapted to the specific environment of clay soil. *C. ciliaris* established with difficulty on clay soil, but when the species does establish, it increases (Van Oudtshoorn, 1999). *C. gayana* is a short-lived perennial grass, which explains the decrease of this species within the third year (Fig. 8.7). The oversown populations from the untreated seed of *D. eriantha*, *P. maximum* and *C. ciliaris* were represented in the seedling, vegetative and reproductive growth stages (Fig. 8.8). *D. eriantha* from untreated seed had the highest number of each growth stage. The *D. eriantha* and *C. ciliaris* from untreated seed had higher numbers in the different growth stages than those from enhanced seed.

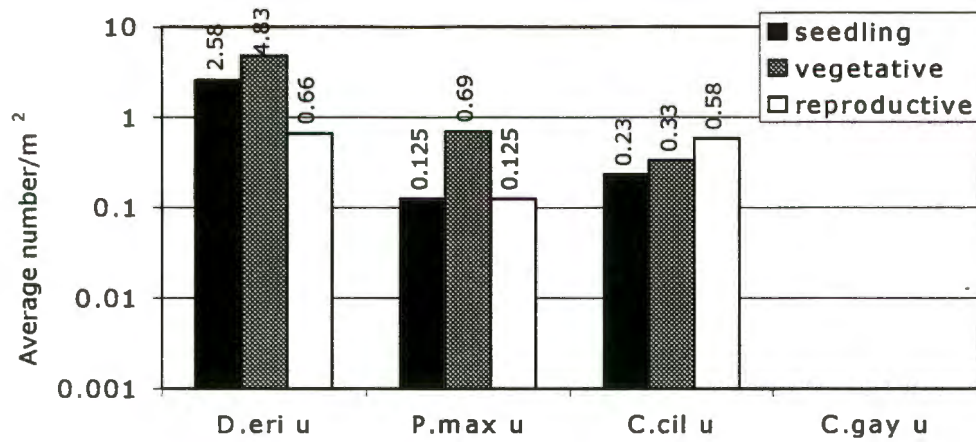


Figure 8.8: The average number of each growth stage of the untreated species sown in at Davidskatnagel.

8.4.5 Soil seed bank analysis

A total of 294 seedlings of at least 18 species germinated from the soil samples during the soil seed bank analysis. The total seedling density varied considerably (8-125 seedlings/m²). The soil seed bank was dominated by *Brachiaria eruciformis* (sweet signal grass). Of the oversown species, only *P. maximum* and *C. gayana* were represented in the soil seed bank. The composition of the soil seed bank was 50% grasses (28% annuals and 22% perennials) 6% geophytes and 44% forbs (Fig. 8.9).

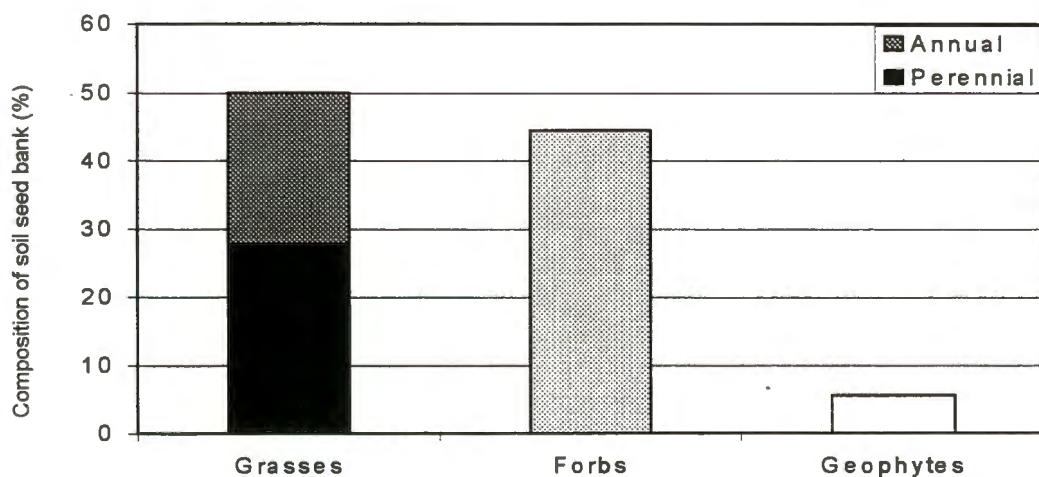


Figure 8.9: The composition of the soil seed bank at Davidskatnagel (1998/1999).

8.4.6 Difference between the control and the oversowing treatment

A number of differences existed between the plots with only a rip plough treatment (control plot) and those with rip ploughing combined with oversowing with either enhanced or untreated seed (Table 8.4, Fig. 8.10). The aim of the control plot was to test the effect of the rip plough treatment on the resident species, with regard to their increase in frequency and diversity. None of the oversown species have spread to the adjacent control plot. *B. eruciformis*, *Dinebra retroflexa* (catstail vlei grass), *Sporobolus iocladis* (pan dropseed), *U. panicoides*, *Eragrostis curvula* (weeping love grass), *T. berteronianus* (carrot-seed grass), *Perotis patens* (cat's tail) and *S. africanus* decreased in the plots oversown with enhanced and untreated seed, as well as in the control plots that were only rip-ploughed (Table 8.3 and 8.4). The frequency and density of *P. maximum* decreased during the period 1996 to 1999 (Table 8.3; Table 8.4). *Chloris virgata* increased (Table 8.3; Table 8.4) and *Eragrostis chloromellans* (narrow curly leaf) increased in the enhanced and untreated plots, but decreased in the control plot. *E. rigidior* increased in the plots oversown with enhanced and untreated seed, as well as in the control plot. *Aristida congesta* (tassel three-awn) decreased in the third year but increased in the fourth year. The rip plough cultivation method caused an increase in either the frequency and/or density of *B. eruciformis*, *Panicum coloratum* (small buffalo grass), *Eragrostis rigidior* and *Aristida junciformis* (Gongoni three-awn). *S. africanus*, *A. congesta*, *U. panicoides* and *C. virgata* were negatively influenced by the rip plough cultivation method.

Table 8.3: The average frequency (%) of the dominant grasses at Davidsskatnagel. Species of less than 1% frequency were not added in this table unless it is a oversown species

	Enhanced			Untreated			Control inside		
	96/97	97/98	98/99	96/97	97/98	98/99	96/97	97/98	98/99
<i>Aristida congesta</i>	7.32	4.3	11.4	6.24	1.2	6.4	13.6	2.3	35
<i>Brachiaria eruciformis</i>	10.7	8.98	8.4	17.8	14	3.8	8.8	3.5	1
<i>Cenchrus ciliaris</i>	14.3	9.67	8	4.77	1	1.33	0	0	0
<i>Chloris gayana</i>	7.5	6.33	4.67	14.2	0.67	4.33	0	0	0
<i>Chloris virgata</i>	0	23.1	30	9.26	14.7	26.4	60.5	63.8	30
<i>Digitaria eriantha</i>	13.9	26.3	34.3	9.83	17.1	8.67	0	0	0
<i>Dinebra retroflexa</i>	4.76	0	0	2	0	0	0	0	0
<i>Eragrostis chloromellas</i>	0	0	7.8	0	0	12	0	0	0
<i>Eragrostis curvula</i>	2.98	6.94	0	1.86	9.74	0	0	3.5	0
<i>Eragrostis rigidior</i>	0	0	5.6	0	0	3.6	0	0	29
Other	14.9	0	0	0	0	0	0	0	0
<i>Panicum maximum</i>	15	12	6.75	26.7	9.3	9.25	0	0	0
<i>Perotis patens</i>	0	6.3	0	0	4.98	0	0	0	0
<i>Sporobolus africanus</i>	0	9.4	0	0	3.58	0	0	16.4	0
<i>Sporobolus iocladis</i>	1.94	0	0	2.96	0	0	8.8	0	0
<i>Tragus berteronianus</i>	0	2.24	0	0	2.18	0	0	0	0
<i>Urochloa panicoides</i>	3.84	8.14	0	5.24	6.78	1.2	4	1.2	0



Figure 8.10: The difference between the field of annual composition on the right and the oversown species on the left. The control plot is at the front of the picture.

Table 8.4: The average density (plants/m²) of the dominant grass species at Davidskatnagel. Apart from oversown species, species with less than one plant/m² were not tabled

	Enhanced		Untreated		Control inside	
	97/98	98/99	97/98	98/99	97/98	98/99
<i>Aristida congesta</i>	6.2	0	2.4	0	34.3	0
<i>Aristida junciformis</i>	0	19.8	0	6.4	0	39
<i>Brachiaria eruciformis</i>	3.6	1.53	16.4	2.93	0.5	0.67
<i>Cenchrus ciliaris</i>	0.5	0.11	0.67	2.11	0	0
<i>Chloris gayana</i>	0	2.56	0	0	0	0
<i>Chloris virgata</i>	46.6	68.4	41.3	54.2	133	58
<i>Digitaria eriantha</i>	2.67	2.78	7.5	7.33	0	0
<i>Eragrostis curvula</i>	1.9	0	3.5	0	0	0
<i>Eragrostis rigidior</i>	0	2.07	0	1.13	0	9.33
<i>Panicum coloratum</i>	0.4	1.47	0.85	0.07	0.25	1.67
<i>Panicum maximum</i>	4.31	0.83	0.94	0.67	0	0
<i>Perotis patens</i>	0	0	1.1	0	0	0
<i>Sporobolus africanus</i>	4.8	0	1	0	9.25	0
<i>Tragus berteronianus</i>	1.3	0	4.5	0	0	0.33
<i>Urochloa panicoides</i>	3.7	0.67	2.3	0.2	5	0



Figure 8.11: Enclosure with restoration treatment of rip ploughing and oversown with *C. ciliaris* on the right and *P. maximum* on the left towards the back of the photograph (1997/1998).

8.4.7 Trajectories over time

The change in species composition over time can be established using gradient analysis. All the sub-plots (including all treatments, seed types and mixtures) over the total sampling period were analyzed with a DCA-ordination technique using DECORANA to identify trajectories of change in composition over time (Hill, 1979; Westoby *et al.*, 1989; Milton & Hoffman, 1994).

Axis 1 of the ordination diagram (Fig. 8.12) represents the change over time in the vegetation from a *C. gayana* and *P. maximum* dominance in 1997 (left of the ordination axis 1) to a *D. eriantha* dominance in 1999 (right of the ordination axis 1). At first the species composition of 1997 (*Dinebra retroflexa*, *C. gayana*, *P. maximum*, *B. eruciformis*) changed to *E. curvula*, *P. patens*, in 1998 and finally in 1999 to a *D. eriantha*, *Bothriochloa insculpta*, *E. chloromellas*, *C. virgata* dominated vegetation composition. Axis 2 represents the divergence in the species composition of the sub-plots. Development occurred towards a *D. eriantha* dominated climax species composition at the bottom of the diagram and sub-plots with an annual grass species composition (*C. virgata*, *S. africanus*, *P. coloratum*) at the top of the diagram. *B. eruciformis* had no effect, because the species occurred in all of the sub-plots.

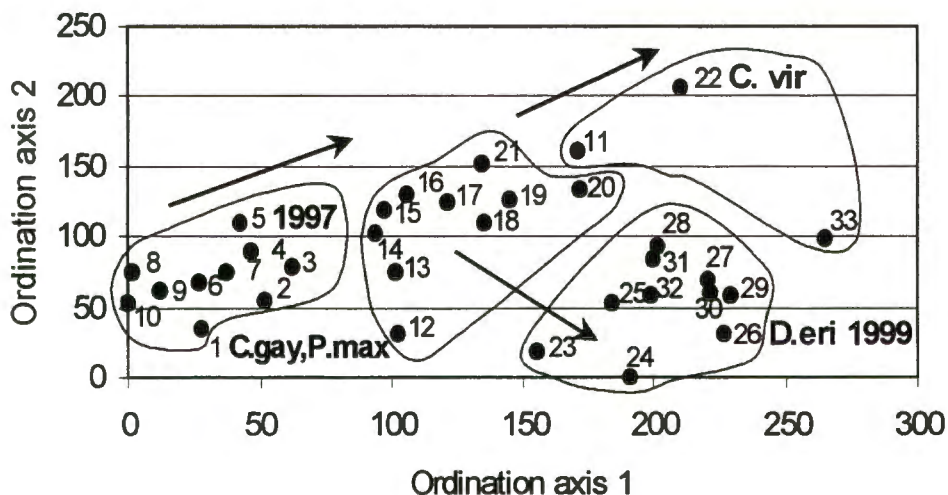


Figure 8.12: Results of a DCA-ordination depicts the development of a *Digitaria eriantha* dominated climax species composition over a period of three years at Davidskatnagel.

Over time, the rip plough and oversowing treatment combined with the exclosure, will change towards a *D. eriantha* dominated species composition, while the exclosure with rip ploughing and no oversowing will stay a vegetation community dominated by the annual grass species, *C. virgata*. The density data, though does not support the results of the DCA ordination, because the DCA ordination is based on the frequency data, which, as you may recall, were surveyed on the rows in which the seed was oversown.

8.4.8 Species richness

Although the vegetation composition prior to the restoration application is not known, the diversity in grass species increased by 8 species in the year after restoration application to a total number of 23 grass species occurring in the study area. The majority of the species declined from 1997 to 1998 due to a lower average rainfall in February (Fig.8.2), indicating that grass vegetation is highly dependant on rainfall and that management strategies should make provision for drier periods.

8.5 Discussion and conclusions

If the laboratory tests are considered, the untreated seed seem to be the best choice for restoration purposes, but compared to the field trials, it seems that enhanced seed of *D. eriantha* and untreated seed of *P. maximum* are most suited for re-seeding in this specific study area (Fig. 8.3 and 8.4), supporting the findings of Advance Seed (Pty) Ltd. and Taylor *et al.* (1998). *C. gayana* and *C. ciliaris* had no seedlings surviving in the field at the time of the survey and therefore are not considered as suitable for reseeding in this specific study area.

The low seedling survival may be explained in the following way: Surveys were conducted in February 1997 and 1998 and in March 1999, influencing the ratio of seedlings to vegetative plants. The number of seedlings that were counted in February would be less than the number of seedlings counted in March. The seedlings mature into adult plants as the season moves on towards March, so that the number of seedlings diminishes and the number of adult plants increase. In other words, March 1999 would show a lower number of seedlings than February 1997, because the seedlings would mature in a month's time. Furthermore, the number of quadrats used in the field influenced comparisons between frequency and density measurements. The rainfall of February 1997 in

which the surveys were conducted was below the average long-term rainfall for February.

The initial mixture of *D. eriantha*, *P. maximum*, *C. ciliaris* and *C. gayana* is more expensive than the mixture that is suited for the area, would in fact be (Fig. 8.4, sub-plot 6). Instead of using all four grass species, only two are necessary. The trial could have been oversown with *D. eriantha* and *P. maximum* alone, bringing the sowing costs down. This is the only mixture where all the constituent species have seedlings surviving in the field. This mixture is therefore recommended for restoration practices in black vertic clay, a sandy-clay-loam texture, a soil with pH of 7 and an average short-term rainfall is 310 mm/yr. Enhanced seed of *D. eriantha*, untreated seed of *C. ciliaris* and untreated seed of *C. gayana* are the species that increased their contribution to the species composition over the study period (Fig 8.5). The species in the study area were not subjected to grazing and therefore the ratio between palatable and unpalatable species increased in the direction of palatable species supporting findings of Kellner (1995). *P. maximum* commonly occurs in shady and moist places making the species, however, unsuitable for these open areas (Van Oudtshoorn, 1999). A decrease of the species can therefore be expected over the long-term. *D. eriantha* from untreated seed, *P. maximum* from enhanced seed and *C. ciliaris* from untreated seed are suited for this area, but not in a mixture (see 8.4.1, Fig. 8.7 to 8.8), because they established sustainable populations, but did not grow well when oversown together. The culms of *C. ciliaris* are up to 1 m long, often decumbent and branched, usually forming roots where the nodes touch the ground (i.e. stoloniferous) (Van Oudtshoorn, 1991, Gibbs-Russell *et al.*, 1990). This stoloniferous nature of *C. ciliaris* pose competitive advantages towards *D. eriantha* and *P. maximum*. *D. eriantha* is also a vigorous grower and has a high competitive ability, suppressing other tuft forming species occurring with it over the long-term.

The soil seed bank is congruent with current literature with regard of the number of species present in the soil seed bank, as well as the structure (the ratio between grasses, forbs and geophytes (Du Toit & Alard, 1995, Tsuzuki & Kanda, 1996 and Akinola *et al.*, 1998). The presence of *P. maximum* in the soil seed bank explains the sustainability of this grass species (Fig. 8.9). Soil from the control plot was used for the soil seed bank analysis in an attempt to verify the original soil seedbank composition. Grass seed usually does not spread more than two meters from the parent plant and that could explain the low representation of the oversown seed in the soil seed bank (Bakker, 2000).

The rip plough cultivation method improved the environment for seedling establishment (in accordance with Davies *et al.*, 1986), but when a perennial grass population was established within a relatively short period of time (e.g. five years), seed of the desirable species was oversown in the areas under restoration (Table. 8.4 and 8.5), supporting Tainton (1981) and Kellner (1995), with regard to intervention in degraded pastures. Oversowing had a positive effect in reducing competition from resident species with the oversown species, because the oversown species developed larger tufts than the resident species, supporting findings of Sheley *et al.* (1999).

The rip plough cultivation method and oversowing treatment successfully established a climax perennial grass cover (Fig. 8.12). Huffaker & Cooper (1995) also discussed the use of plant succession in restoration practices. If a vegetation composition with perennial, big tufted, palatable species is required to increase the production and grazing capacity of the sward, the restoration treatment recommended should include a cultivation method and the oversowing of *D. eriantha* seed. A well established pasture can, however, only be expected after a 3-4 year period.

The rainfall of the year used to study the seedling survival rate was below the long-term average rainfall of the area (Fig. 8.1). Subsequently, seedling survival rates were not higher than 2% in the second year after the restoration treatment was applied (See also chapter 5 and 7). All the oversown species, except *D. eriantha* from enhanced seed, decreased over the study period. This decrease in frequency is in line with the rainfall patterns for the survey dates, which for 1997 and 1998 was just below the average long-term rainfall of the area (60 mm/month and 90 mm/month, respectively). The rainfall for March 1999, however, was far below the average long-term rainfall of the area (35 mm/month). The increase in the frequency of *D. eriantha* from enhanced seed between 1998 and 1999 might be explained by the slight peak of rainfall in February 1999, as well as the above average rainfall of November and December 1998.

The DCA ordination trajectories based on the vegetation change over time showed a distinct development of two plant communities. The *C. gayana* - *P. maximum* dominated community of 1997 develop towards an annual grass, *C. virgata* dominated community and a perennial *D. eriantha* dominated community. The annual community was the control plot where no oversowing occurred, while the perennial community included all the plots where oversowing did occur.

Oversowing combined with rip ploughing is definitely more effective in restoring a sward to a palatable, perennial grass composition than just rip ploughing on its own. This conclusive part of the project is a clear indication that once the soil seed bank (i.e. one of the resource bases for grass species) is depleted, restorative actions must include an oversowing treatment. The oversowing treatment also partly contributed to the increase in the species richness over the four years of the study (Table 8.4), supporting findings by Dzwonko & Loster (1998). If oversowing is not included in the restoration technologies for areas with poor seed banks, the attainment of sustainability in the restored systems is impossible.

8.6 References

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Chapter 9. General discussion and conclusions

9.1 Introduction

As part of a larger project (see Section 4.1, especially 4.1.2 and 4.1.3, Chapter 4), seed of five perennial climax grass species, i.e. *Panicum maximum*, *Chloris gayana*, *Cenchrus ciliaris*, *Anthephora pubescens* and *Digitaria eriantha* were sown in degraded pastures with the aim of establishing preferred vegetation in these degraded areas. Quantitative frequency and density measurements were undertaken over a period of five years to describe the establishment and dynamics of the sown-in grass species. Two types of seeds, namely treated (enhanced) and untreated seed (see Section 2.3, Chapter 2), were used to establish whether enhancement benefited the sown seed or not. The different grass species were sown in different mixtures in the four study areas to find the grass mixtures most suited to the specific environmental conditions. The presence of seed of the sown-in and other species in the soil seed bank was tested after three years through a soil seed bank analysis (Sections 2.6, Chapter 2 and 4.1.2, Chapter 4). The above mentioned study had the following aims:

- 1) The evaluation of the sustainability and dynamics of the five grass species used in an oversowing and restoration application in four degraded semi-arid rangelands.
- 2) The evaluation of the increase in the richness of the grasses after the restoration application, using total grass composition information and comparing the information from the different years to one another.
- 3) The evaluation of the improvement in the condition of the vegetation in the rangelands by processing frequency data using the Integrated System for Plant Dynamics (ISPD) (Bosch *et al.*, 1992).

9.2 Laboratory germination rate versus field seedling survival of enhanced and untreated seed

See Sections 5.4.1 in Chapter 5, 7.4.1 in Chapter 7 and 8.4.1 in Chapter 8.

Seed enhancement increased the survival rate of agricultural crops such as *Brassica* spp. (Taylor *et al.*, 1998), but this had not been established scientifically for grass seeds, particularly under field conditions. In this study using grass seed, the untreated seed have a higher germination rate in the laboratory,

corresponding with findings for other agricultural crops. In the field, however, the enhanced seed had the higher seedling survival rate with some exceptions, finally proving scientifically that enhanced seed does increase grass seedling survival in the field. The exception is *C. gayana*, where the enhanced seed had a lower seedling survival than the *C. gayana* from untreated seed at Tweefontein. It can be concluded from these findings that enhanced seed is the better choice for seed application in the field. At Kromspruit sub-plots were sown with enhanced seed plus 50% more seed, with the intention of placing equal amounts of viable enhanced seed and untreated seed in the soil. Enhanced seed contains less seed per gram than untreated seed because the coating materials increase the weight (see Section 2.3, Chapter 2). This enhanced seed plus 50% more seed had a higher seedling survival rate in the field than the sub-plots sown with the normal recommended rate of enhanced seed. In practice one should rather use enhanced seed plus 50% more seed for restoration purposes in soil of norite origin, combined with the following habitat characteristics. A northern aspect, vertic clay soil overlaid by yellow-red sand, a 23% clay content, a pH of 7 - 8, a 517 mm/yr. short-term rainfall and temperature varying between 11 °C and 27 °C as in the case at Kromspruit. An increase in the amount of seed, however, also entails higher costs, which have to be considered on the assessment of the economic viability of the restoration treatments.

9.3 Richness of the grasses

See Sections 5.4.8 in Chapter 5 and 8.4.8 in Chapter 8.

An increase in species richness supplies an ecosystem with resilience because of niche specialisation by different grass species. This resilience provides the ecosystem with the sustainability necessary for long-term utilisation of high quality grasses (Gliessman, 1995; Hoffman *et al.*, 1999). In this study, the richness of the grasses of each study area increased over the period of 1995 to 1999, supporting results of Dzwonko & Loster (1998). At Totiuskraal, where the soil was the most eroded, an increase of only 8 grass species occurred, supporting Snyman & Fouche's (1991) findings that veld condition, rather than rainfall, is an important factor controlling water-use efficiency (above-ground phytomass production) and richness. The other study areas initially covered with only undesirable annual grass species, showed an increase of 11 to 14 grass species. The conclusion is that the increase in species richness may contribute to a higher sustainability over time in restoration if cultivation and oversowing technologies are applied.

9.4 Grass seed mixtures

See Sections 5.4.1 in Chapter 5, Section 7.4.1 in Chapter 7 and 8.4.1 in Chapter 8.

Specific grass mixtures were suited for the specific environmental conditions at each of the study areas, in the North West Province of South Africa. The following results support Van Oudtshoorn (1999), Gibbs-Russell *et al.*, (1990), Jones (1985) or Van Den Berg (1999) with regard to species adaptability to specific environmental conditions. As an overview the habitat preferences of the oversown species are noted and will be followed by a discussion of the habitat at the different study areas and a recommendation of a suitable grass mixture.

C. ciliaris are adapted to dry areas (300 – 1000 mm/yr.) and is very drought resistant. The species can tolerate high temperatures and some flooding, but is not adapted to acid soils. The species prefer sandy soil as well as other well-drained soils. It can grow in loam and clay soil as well and prefers a pH of between 5 and 6. The species is susceptible to frost.

C. gayana is adapted to a wide range of soils, with a preference for loam soil. The species is drought tolerant and not well adapted to high rainfall (but grows with 600 – 1000 mm/yr.) or poorly drained clay. The species is not well adapted to very acid soils, but prefers a pH of between 5 and 6. The species is tolerant of trampling.

D. eriantha is also adapted to a wide range of soils, especially sandy and rocky soil in the drier parts, and moist soil adjacent to marshy areas. A pH between 5 and 6 is ideal for this species. *D. eriantha* is not frost tolerant, though the frost intolerance do no pose a detrimental problem. *D. eriantha* is excellent hay in the winter time when temperature are below freezing point. The species occurs mainly in undisturbed field and has excellent drought resistance.

P. maximum is also adapted to a wide range of soils, but prefers the fertile shadows of loam and clay soil under trees and shrubs. Rainfall ideal for the species are 500 mm/yr. and more. Optimal pH is between 5 and 6. The species is drought tolerant, but not frost tolerant. This shade loving species often occur with *D. eriantha*.

A. pubescens occurs in undisturbed sandy soil, but can also occur in loam and stony soil at a pH of 5 to 6. Optimal rainfall is 250 to 650 mm/yr.. The species has an excellent drought tolerance.

Kromspruit and Davidskatnagel are similar in environmental characteristics (low rainfall (LTR : 577 mm/yr.), extreme temperatures (-5 °C to 38 °C), 945 m above sea level, black vertic clay (between 20 and 35% clay), sandy-clay-loam texture soils and pH levels between 7 and 8). Most of the sown in species are adapted to this area, except for *C. ciliaris* and *A. pubescens* which prefer more sandy soils, such as the southern part of the Kromspruit study area. *C. ciliaris* establish with difficulty in high clay soils. As *P. maximum* is a shade loving species, this grass would probably be of short-term value, when sown in areas where shade is not abundant. This species must be associated with trees or shrubs. The grass species that are recommended for oversowing in mixtures, in similar areas as Kromspruit and Davidskatnagel, are *D. eriantha*, *C. gayana*, *C. ciliaris* and *P. maximum*. Another species to consider is *Eragrostis lehmanniana*, since this species became the dominant species over time in one of the vegetation groups as shown on the DCA-ordination graph (Figs. 7.15 and 8.12). The reason for the choice of *E. lehmanniana* and not *C. dactylon*, *C. virgata*, *E. rigidior* or *A. congesta* is that the latter four species are either invasive or unpalatable, which is directly against the aims of this study.

The Totiuskraal study area had a higher long-term average rainfall than Kromspruit and Davidskatnagel (617 mm/yr.) and a more sandy textured soil with a pH of 5. Temperatures ranged between -8 °C and 36 °C which is lower than the previous two study areas. The sandy textured soil is ideal for grass species such as *C. ciliaris* and *A. pubescens*, as depicted in the DCA-ordination (Fig. 6.8). These two species are then recommended for use in a mixture in similar habitats.

At the Tweefontein study area, the low long-term average rainfall is 491 mm/yr., and the temperature varied between 0 °C and 37 °C for the period 1995 to 1999. The soil texture has a high silt content and a clay percentage of 25%, and a pH of 6 to 7. The average short-term rainfall (596 mm/yr.) was higher than the average long-term rainfall, during the study which favoured the establishment of a species such as *P. maximum*. The grass species mixture that is recommended for similar environmental conditions as this study area is therefore *D. eriantha*, *C. gayana* and *P. maximum*.

9.5 Frequency and density

See Sections 5.4.2, 5.4.3, 5.4.4 in Chapter 5, 6.4.1 in Chapter 6, 7.4.2, 7.4.3, in Chapter 7 and 8.4.2, 8.4.3 and 8.4.4 in Chapter 8.

The perennial grasses' frequency and density increased in the wetter years in this semi-arid, unpredictable environment, supporting Williams (1970) and Walker *et al.* (1996). This increase only occurred when the grass was adapted to the specific environmental conditions (see Section 9.4, Van Oudtshoorn, 1999, Gibbs-Russell *et al.*, 1990, Table 3.2). In most of the study areas, the frequency and density of the grass species decreased during the drier years. At Tweefontein, the frequency of the sown-in species decreased, except for *D. eriantha* and *C. ciliaris*. At Totiuskraal, the frequency was stable for enhanced *C. gayana*, *C. ciliaris* and untreated *P. maximum*. The frequency increased for enhanced *A. pubescens* and decreased for untreated *C. gayana*, *C. ciliaris*, *A. pubescens* and enhanced *P. maximum*. At Kromspruit, the frequency of the oversown species increased. At Davidkatnagel, the frequency decreased, except for *D. eriantha* and *C. ciliaris*. When the frequency and density of a grass species increases, the specific species becomes more sustainable due to a larger or greater contribution to the total grass composition. Theoretically, the more plants there are of a species, the greater the survival of that species can be expected (i.e. if the number of plants are below the number which will result in intra-specific competition, Begon *et al.* 1990). The argument was that more individuals contribute seed or more opportunities for vegetative growth for the next generation than fewer individuals will (Barbour *et al.* 1987). Depending on the rainfall patterns in the growing season, the density and frequency of the populations of the grass species increased or decreased. Overall, there is an increase in the frequency and density of *D. eriantha* and a decrease in the frequency and density of *P. maximum*, *A. pubescens*, *C. ciliaris* and *C. gayana* over the four years of the study period, as well as over the four study areas.

9.6 Growth stages

Following the recruitment, growth and death of plant genets through time and space is one way of measuring the sustainability of a plant population. In this study, sustainability was indicated by the presence or absence of the species in all three growth stages, namely seedling, vegetative and reproductive stage. The argument is that a species will only reproduce when environmental conditions are favourable for the species survival. Supporting this argument, specific

environmental cues trigger seed of a species to germinate and establish, so that a species that is represented in the seedling growth stage implies adaptation to the specific environmental conditions. This adaptation, combined with correct management practices and favourable climatological conditions, increases the chances that the particular species will be present in the study area over a long-term period.

At Tweefontein the species represented in the seedling, vegetative and reproductive growth stages in the season of 1996/1997 for the enhanced and the untreated seed were *D. eriantha* and *C. gayana*. These two species then, by definition, have sustainable populations, and are deemed as the species that will form part of the species composition over the long-term. *C. gayana*, though, tend to decrease from the third year after establishment has a valuable role as a nursing plant for creating suitable microhabitats for the perennial grasses such as *D. eriantha*. *C. ciliaris* and *P. maximum* were not represented in all three growth stages, and are therefore not considered as sustainable populations.

At Kromspruit, *D. eriantha*, *C. ciliaris* and *C. gayana* of the untreated seed were represented in all three growth stages in the 1997/1998 season. These three species are sustainable – interesting to note that *C. ciliaris*, which is adapted to more sandy soil formed a sustainable population in this clayey soil that was overlain with yellow-red sand in the southern part of the area. Of the enhanced plus 50% more seed, *D. eriantha*, *C. ciliaris* and *P. maximum* were represented in all three growth stages and form sustainable populations. None of the species of the enhanced seed were represented in the three growth stages. The survey timing and technique might have been at the wrong time and insufficient amount (see Section 9.11).

D. eriantha and *P. maximum* of the enhanced seed at Davidskatnagel were represented in the seedling, vegetative and reproductive growth stages and formed sustainable populations. These two species will most probably be part of the species composition of the study area over the long-term, even though it is expected that *P. maximum*, which is shade loving, will in the open, sunny areas, not be sustainable. *C. ciliaris* and *C. gayana* of the enhanced seed were represented in two of the three growth stages and can therefore not be regarded to form sustainable populations over the long-term. Of the untreated seed only *C. gayana* were not represented in the three growth stages, but *D. eriantha*, *C. ciliaris* and *P. maximum* formed sustainable populations. The three latter species

will most probably form part of the long-term species composition in the study area, although *P. maximum* again may decrease over the long-term.

9.7 Soil seed bank

See Sections 5.4.5 in Chapter 5, 6.4.3 in Chapter 6, 7.4.4 in Chapter 7 and 8.4.5 in Chapter 8.

Long-living perennial grasses seldom form persistent seed banks (Barbour *et al.*, 1987, see Section 2.6.2, paragraph four and five, Chapter 2) and therefore pastures should be managed to allow perennial grasses to annually add seed to the soil seed bank. The species used in this study, flower in the months August to May (Van Oudtshoorn, 1999), which is also the growth period of the grasses and time of summer grazing. It is therefore recommended to apply rotational grazing for pastures and to withdraw grazers between February and March, allowing the species to form seed (Edwards and Crawley, 1999b). Rotational grazing rests a particular pasture and aids in seed formation, organic material deposition and overall health of the pasture (Le Roux, 1998). Withdrawal of grazers should be coupled with the second rain pulse of the summer season (see Section 3.6, Chapter 3). Of the sown-in seed, *D. eriantha*, *C. gayana* and *P. maximum* appeared in the soil seed bank, but not seed of *A. pubescens* and *C. ciliaris* at Totiuskraal, which is rather peculiar since these are the two species that established well at Totiuskraal. For this reason, several soil seed bank analyses are advised. Dormancy of the grass seeds could have caused it not to be recorded in the time when the study was carried out. Other perennial grass seed that were not sown into the study areas but that appeared in the soil seed banks include *Eragrostis curvula*, *Setaria* sp., *Hyparrhenia hirta*, *Themeda triandra*, *Digitaria agyrogapta* and *Sporobolus africanus*. Annual grasses included *Aristida junciformis*, *Brachiaria eruciformis*, *Chloris virgata*, *Eleusine coracana*, *Setaria pallida-fusca*, *Tragus berteronianus*, *Urochloa panicoides*, *Aristida congesta*, and *Brachiaria serrata*. It is clear that a very rich soil seed bank was present prior to the restoration treatment and that soil disturbance triggered the germination of most of these species, supporting findings by Bakker *et al.* (1996). Each specific study area had a specific group of dominant plant types; e.g. more forbs occurred in the Kromspruit area (Fig. 7.14, Chapter 7), while more grasses occurred at Davidskatnagel.

9.8 Total species composition as influenced by the rip plough cultivation method, followed by a number of recommendations

See Sections 5.4.6 in Chapter 5, 7.4.5 in Chapter 7 and 8.4.6 in Chapter 8.

At the Tweefontein study area, the frequency of species with a low ecological status such as *Cymbopogon plurinodis*, *Eragrostis racemosa*, *Aristida congesta*, *Melinis repens* and *Elionurus muticus* decreased because of the rip plough cultivation method. Considering the soil and climatological information and the grass species that had benefited from the rip plough cultivation method, the following species are recommended for restoration of degraded areas of similar environmental conditions: *S. sphacelata*, *E. curvula*, *T. triandra*, *P. maximum*, *C. gayana*, *E. chloromelas* and *C. ciliaris*. A mixture of these grasses covers a wide range of uses, providing highly palatable grasses (*T. triandra*, *P. maximum* and *C. ciliaris*) supplementary fodder (*S. sphacelata*, *E. curvula* and *E. chloromelas*) and stabilising agents (*C. dactylon*), and increasing the overall species richness and ecological stability. Seeds of these grass species are, however, not easily obtainable in large quantities. Seed merchants do not sell most of these seeds and harvesting the seeds manually by the landuser him/herself is too labour- and cost intensive. This causes only seeds that are available from seed companies to be used for restoration purposes, especially in South Africa, though Bakker *et al.* (1996) and Lochner (1997) harvested the seed they used in their experiments. The seeds bought from seed companies are often species more adapted for the establishment of cultivated pastures of which the seed beds are prepared with high fertilizer inputs, and not for restoring degraded natural pastures. Purchasing of seeds from merchants also makes restoration very costly over the short-term. Choosing the correct and most adapted species and seed mixture for a particular environment is therefore of the utmost importance.

Furthermore, instead of oversowing all five species of the grass mixtures used in the study, only *C. gayana* (untreated seed), *D. eriantha* (enhanced seed) and *P. maximum* (enhanced seed) can be used, because the other two species did not perform as well in this habitat.

At Kromspruit, the rip plough cultivation method led to a decrease in the frequency and density of *Chloris virgata*, *Urochloa mosambicensis*, *C. dactylon* and *Brachiaria eruciformis*. However, the density of some species increased such as *D. eriantha*, *P. maximum*, *Eragrostis rigidior*, *Setaria nigrirostris*, *A. congesta* and *Bothriochloa insculpta*. As mentioned for Tweefontein, the former species are

adapted to this specific area's soil and climatological characteristics. *D. eriantha*, *P. maximum* and *B. insculpta* could be used in a mixture when restoring areas of similar environmental conditions. There seems to be a year time-lag in the increase in species frequency and the amount of rainfall the area received. This is probably due to the clayey soil type with its high water holding capacity (Bruce, 1998). The relatively small number of perennial climax grass species suitable for this area is directly linked to the rainfall patterns of the area. The *D. eriantha* and *C. ciliaris* showed time lags with the rainfall of the study area. In support of previous studies (Peel *et al.*, 1991, Snyman & Fouche, 1991 and Milton, 1994) rainfall is the main driving force in the species composition of semi-arid areas and seedling mortality is drought induced. This means that low rainfall will be coupled with low frequency measurements. An interesting development is that of species, which do not decrease with decreased rainfall, which suggests those water resources other than rainfall is available to the particular species. Such species included for example *P. maximum*, *D. eriantha* (from untreated seed) and *C. ciliaris* (from enhanced seed) at Kromspruit.

At Davidskatnagel, the rip plough cultivation method lead to a decrease in the frequency and density of *B. eruciformis*, *Sporobolus ioclados*, *C. virgata*, *Urochloa panicoides*, *E. curvula* and *Sporobolus africanus*. The rip plough cultivation method led to an increase in the frequency and density of *A. congesta* and *E. rigidior*. In semi-arid regions, perennial grasses mainly reproduce through seed. In accordance with Baskin & Baskin (1998), it was found that the persistence of perennial climax grass species are dependent on seedling recruitment, and the role of the soil seed bank in this recruitment process was highlighted. Seed of *P. maximum* that became part of the soil seed bank will have benefits for this pasture in the future. The importance of the soil seed bank also raises the issues of proper grazing management, whether the traditional nomadic use of communal land can be managed sustainable and/or whether the focus should shift to the camp system commonly used on commercial farms. Should the traditional nomadic use be followed, water holes can be spaced in such a way that two or three grazing areas exist which can be rotated throughout the year. Flat stones against trampling can be packed at least 4 m around the water holes. Where the communal grazing land is too small for water hole management, areas can be debused and the thorn bushes used as fences to direct animal movement. Relatively unpalatable grass fields should be separated from palatable grass fields. The palatable patches can be rotationally grazed, alternatively allowing rest periods during the flowering, seeding and seedling establishment periods. The

shepherds can also pluck ripe seed and sow it in areas where there are no palatable plants growing, seeing to it that some of the seed fall inside the canopy of thorn shrubs, which will serve as a safe site and a dispersal core. The unpalatable grasses can be used for thatch or traditional art forms; profit from such a market could be ploughed back into the upliftment of the community as a whole. The scope of this project does not allow for the social aspects behind knowledge transferral, but future studies would benefit from such an added social aspect.

9.9 Change in vegetation condition

See Sections 5.4.7 in Chapter 5, 6.4.4 in Chapter 6, 7.4.6 in Chapter 7 and 8.4.7 in Chapter 8. The trajectories of these DCA-ordination graphs (using the DECORANA option in the ISPD computer package) depict the change in the composition of the different pastures and thus the subsequent vegetation condition of the study areas.

According to Van Oudtshoorn (1999), grasses are adapted to specific environmental conditions. When the environmental conditions change, the grass species composition should also change. This sensitivity to specific environmental conditions makes grasses good indicators of range condition and they are therefore used as such. Veld condition (or vegetation condition) is usually based on the abundance of a certain grass species classified according to 'ecological status' (Janse van Rensburg & Bosch, 1990). The grass species sown in the study areas could all be regarded as Decreaser type of species (Van Oudtshoorn, 1999), i.e. grass species that are abundant in veld of good grazing condition, but which decreases in veld that is under- or overutilized. They are also all palatable climax grass species. The fact that the species composition in the study areas improved proves that the restoration of the veld condition had a positive effect on the pasture. The grazing capacity should therefore also improve. In all the cases, the grass species composition of the study areas improved over the period of five years after the restoration application. At Tweefontein and Davidskatnagel where *D. eriantha* was sown in, the grass communities became *D. eriantha* dominated. In the case of the Totiuskraal study area, *C. ciliaris* and *A. pubescens* became the dominant grasses. And *D. eriantha* was not oversown at Totiuskraal. At Kromspruit the dominant species are *C. dactylon* and *C. virgata*, but the perennial grass that became dominant is *D. eriantha*.

The development of the vegetation condition of each study area over the study period of five years can be examined and worthwhile conclusions drawn from it. At the Tweefontein study area, two groups developed in the first year after the rip plough and oversowing treatments (Fig. 5.14). The one group was dominated by *C. ciliaris* and the other group by *C. gayana*. *C. gayana* is stoloniferous (Van Oudtshoorn, 1999). Stoloniferous species usually increase in open, bare areas such as was the case for *C. gayana* after the rip plough treatment in the season of 1995/1996. In 1997, a transition group with *P. maximum* as the dominant species developed, probably due to the higher moisture content of the microhabitat formed by the previous two species on the microhabitat. The *D. eriantha* was the dominant species in the last year of the study period (1999) and the two vegetation groups of 1995/1996 therefore merged towards a *D. eriantha* dominated vegetation condition.

The vegetation condition of the Totiuskraal study area developed from an annual grass composition in 1995 into two groups, the one dominated by *A. pubescens* and the other *C. ciliaris* group in 1999 (Fig. 6.8). Both these species are adapted to the more sandy soil of the study area and this adaptation contributed to the species ability to become the dominant species of the vegetation towards the end of the study period.

The vegetation condition of Kromspruit also developed from an annual grass composition dominated by *C. virgata* (1996) to a perennial grass composition, with two groups dominated by either *E. lehmanniana* and *D. eriantha* (1998, Fig. 7.15). As mentioned, *D. eriantha* is adapted to a wide variety of soils and is also the major species used in cultivated pastures (Van Oudtshoorn, 1999). *E. lehmanniana* is adapted to similar habitat than *D. eriantha* (Van Oudtshoorn, 1999); this species is not as palatable as *D. eriantha*, though, but is also used as pasture grass (Van Oudtshoorn, 1999). The control plot which was rip ploughed, but not oversown, however, were still characterised by *C. dactylon* and bare ground even in the third year after the restoration application (no. 43 in Fig. 7.15). During the first year however *C. virgata*, *C. dactylon* and *B. eruciformis* was still much abundant after which *C. dactylon* became dominant. This can probably be ascribed to the to high rainfall in the spring of 1998.

Davidskatnagel's vegetation condition changed from a dominance by *C. gayana* and *P. maximum* in 1997, two years after the restoration methods were applied, to either a *C. virgata* dominance or a *D. eriantha* dominance in 1999. A transition

vegetation condition was characterised by *C. virgata* and *D. eriantha* in 1998. This implies that *C. gayana* decreased from the third year onwards as Van Oudtshoorn (1999) states, and *D. eriantha* increased from 1998 onwards. The vegetation condition of the control plot inside the enclosure did not change over the study period, implying that the rip plough cultivation method in this case is not effective without the oversowing of perennial grass species. The soil seed bank was most probably depleted.

Gradient analysis describes the change of vegetation condition over time relatively well and therefore it is profitable to use ordination techniques such as DCA-ordination (DECORANA), as is found in the computer package ISPD (Integrated System for Plant Dynamics, Bosch *et al.*, 1992).

9.10 Economical implications

The use of several grass species in a mixture can be expensive (Table 2.2). Choosing species adapted to a specific habitat above a random species list can decrease the economical input necessary for restoration practices. Costs can be cut by reducing the number of seeds used in the oversown treatments. Instead of sowing, for example, 1kg/ha of five possibly suited grass species each, a mixture of 0.3kg/ha of each of three specifically adapted species should be sufficient for the establishment of sustainable, perennial populations. Another way to cut costs is to sow only species that are adapted to a certain habitat. Often a seed mixture is recommended which includes seeds of grasses not adapted for a certain area, making restoration practices with oversowing expensive. At Tweefontein, for example, *C. ciliaris* and *A. pubescens* were not part of the species composition at the end of the study period in 1999 due to unadaptability and can therefore be ignored in future mixtures used for oversowing treatments. This action would decrease the economical input and the oversowing mixture would be less expensive and therefore more acceptable to land users. The same argument holds for the other study areas. At Totiuskraal, two (*C. ciliaris* and *A. pubescens*) instead of four species could have been sown (Fig. 6.8). At Kromspruit, instead of sowing four species (*D. eriantha*, *Chloris gayana*, *C. ciliaris* and *P. maximum*), only *D. eriantha* could have been sown, bringing down the costs considerably (Fig. 7.15). The same applies for the Davidskatnagel study area. When the oversown species has established, the grazing capacity of the area improves so that more animals can graze on the pasture area than prior to the restoration treatment.

9.11 Shortcomings to address in future studies of the same type

After the completion of this study, the following recommendations are proposed for future studies of this nature.

- Seasonal seedbank structures should be investigated over longer periods of time to establish the turnover rate of the total population of a grass species. This should be combined with the senescent plants, which would force one to mark specific plants and follow their development in the field (Snyman & Fouche, 1991). The layer of the seedbank on top of a sterilised medium should not extend 1 cm.
- The number of seed used in the germination tests were found to be inadequate, the method insufficient. Whenever germination tests are part of a project, it is advisable to attend the Seed Analyst Course at the Seed Control Directorate of Genetic Resources prior to such germination tests.
- Two or three frequency, density and environmental surveys per growing season would enable a better interpretation of the relationships between vegetation and environment.
- Measuring organic content of the soil on a yearly basis could indicate the rate at which organic material is returned to soil that was previously degraded.
- Yearly biomass measurements would have given a quantitative picture of the production of such a restored pasture.
- The not oversown grass species that increased over the five years are worthy of further study for use in restoration practices, since they obviously benefited from the rip plough cultivation and attributed to the richness and stability of the current vegetation composition of the pastures. For the most part, seed of these species are, available from Eko-Rehab¹.
- The use of five or more 0.5 m x 0.5 m quadrates per sub-plot in order to draw clearer correlations between frequency and density results of species establishment.
- The use of highly interested, motivated and willing staticians are advised primarily prior to the start of a project.

Further interesting questions that can be investigated in future research are:

1. Reaction of seed coatings with soil-water chemistry and it's influence on the caryopses and subsequent germination.

¹ ✉ Institute of Ecological Rehabilitation, P/Bag X6001, PU for CHO, Potchefstroom, 2520.

2. To measure the extent of loss of seed sown in through seed predation?

9.12 References

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