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**MONITORING THE SUCCESS OF AN OLD-FIELD
REHABILITATION TRIAL IN THE WINTER RAINFALL SUCCULENT
KAROO: THE EFFECT OF *OXALIS PES-CAPRAE***

THIS THESIS PRESENTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN
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By

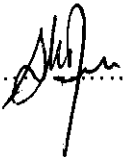
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December 2004

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Dr Léanne L. Dreyer

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that it has not previously in its entirety or in part been submitted at any university for a degree.

Signature: .....

Date: 25/11/2004

Abstract

The main aim of an old field rehabilitation trial initiated in 2000 was to find a solution to the rehabilitation process for approximately 90 000 ha of unutilised land in the Little Karoo, South Africa. Depending only on a natural succession process to restore unutilised old fields would mean that the period of recovery would be longer than the life span of an average farmer. The trial, initiated by Witbooi in 2000 aimed to see how human intervention can facilitate the process of rehabilitation of old-fields. Three years later, the trial was again monitored to evaluate the success of reseeded indigenous species and method of cultivation in the rehabilitation process. A second objective was based on a result of Witbooi (2002) who showed that there was a tendency of *O. pes-caprae* to invade disturbed areas, and aimed to evaluate the effect of this species on the rehabilitation process.

Seven indigenous species were reseeded in 2000, of which only four species germinated and survived to the present. These surviving species are *Pteronia incana* Burm Dc., *Tripteris sinuata* DC., *Ehrharta calycina* SM and *Chaetobromus dregeanus* Nees. The highest level of recruitment in 2001 was recorded for *T. sinuata* followed by *P. incana*, *E. calycina* and *C. dregeanus*. In September 2003, three years after the trial was initiated, the highest number of surviving seedlings were of *T. sinuata* followed by *E. calycina*, *C. dregeanus* and *P. incana*.

Five different cultivation methods were used to enhance the germination rate and survival of seedlings. The number of seedlings that survived differs according to the cultivation methods and soil type. *Tripteris sinuata* had the highest number of surviving seedlings in all cultivation methods off-heuweltjies. *Tripteris sinuata* was therefore selected to analyse the effect of various cultivation methods.

The second objective was to study the impact of *Oxalis pes-caprae* on species diversity in restored old fields by assessing its ability to disperse in old fields under different cultivation

methods. The multivariate ANOVA results showed that there was a significant difference in the density of *O. pes-caprae* between on and off heuweltjies (sites) and treatments (cultivation methods).

There was a significant difference in the density of *O. pes-caprae* between cultivation methods. A Post Hoc LSD test showed a significant difference in the density of above-ground *O. pes-caprae* plants between control sites (no disturbance) compared to those sites that underwent some sort of soil disturbance. There was, however, no significant difference in the abundance of *O. pes-caprae* on plots that underwent some sort of disturbance (i.e Cleared vs Tilled vs Disked vs Ploughed sites) on heuweltjies.

There was a significant difference in the number of *O. pes-caprae* bulbs collected between blocks (on and off-heuweltjie) and significant differences between cultivation methods. There was also a significant difference in bulb diameter between cultivation methods when compared between on and off-heuweltjie sites. The bulbs were classified into four measurement classes. The highest number of small (2-5 mm diameter) and medium (5-8 mm diameter) sized bulbs were found in the Tilled cultivation method. In contrast the Control treatment (uncultivated) had the highest number of large sized bulbs (14-17 mm diameter) and medium bulbs size categories.

In conclusion, *T. sinuata* has the potential to be used for rehabilitation of old fields in combination with Tilled cultivation method. Attention should be paid to the effect of *O. pes-caprae* especially on heuweltjies where this species showed a complete dominance in the rehabilitation trial.

Opsomming

Die hoof doel van 'n ou veld rehabilitasie eksperiment wat in 2000 geïnisieer is was om 'n oplossing te vind vir die rehabilitasie proses vir ongeveer 90 000 ha onbenutte land in die Klein Karoo, Suid Afrika. Indien daar slegs op natuurlike suksessie prosesse staatgemaak word om die onbenutte ou lande te restoreer, sou dit beteken dat die periode van herstel langer sou wees as die lewensverwagting van die gemiddelde boer. Hierdie eksperiment, wat in 2000 deur Witbooi geïnisieer is, het gepoog om te bepaal hoe menslike inmenging die proses van rehabilitasie van ou velde kan fasiliteer. Drie jaar later is die eksperiment weer gemonitor om die sukses van die teruggesaaide inheemse spesies en bewerkings-metodes in die rehabilitasie proses te evalueer. 'n Tweede doelwit is gebaseer op 'n resultaat van Witbooi (2002) wat aangetoon het dat daar 'n neiging was vir *O. pes-caprae* om versteurde areas binne te dring, en het dus gemik om die effek van hierdie spesie op die rehabilitasie proses te evalueer.

Sewe inheemse spesies is in 2000 teruggesaaï, waarvan slegs 4 spesies ontkiem en oorleef het tot die hede. Hierdie oorlewende spesies is *Pteronia incana* Burm Dc., *Tripteris sinuata* DC., *Ehrharta calycina* SM en *Chaetobromus dregeanus* Nees. Die hoogste vlak van werwing in 2001 is vir *T. sinuata* aangeteken, gevolg deur *P. incana*, *E. calycina* en *C. dregeanus*. In September 2003, drie jaar na die aanvang van die eksperiment, was die hoogste getal oorlewende saailinge dié van *T. sinuata*, gevolg deur *E. calycina*, *C. dregeanus* en *P. incana*.

Vyf verskillende bewerkings-metodes is gebruik om ontkiemingstempo en saailing oorlewing aan te help. Die aantal saailinge wat oorleef het varieer volgens die bewerkings-metode wat gevolg is en die grondtipe. *Tripteris sinuata* het die grootste aantal oorlewende saailinge

gehad in al die bewerkings-metodes af van heuweltjies. *Tripteris sinuata* is daarom geselekteer om te analiseer vir die effek van verskillende bewerkings-metodes.

Die tweede doelwits was om die inpak van *Oxalis pes-caprae* op spesie-diversiteit in die gerestoreerde ou land te bepaal deur die vermoë van hierdie spesie om in ou velde te versprei onder verskillende bewerkings-metodes te evalueer. Die multi-veranderlike ANOVA resultate het aangetoon dat daar 'n beduidende verskil in *O. pes-caprae* digtheid tussen heuweltjie en nie-heuweltjie (persele) en verskillende bewerkings-metodes was. Daar was 'n beduidende verskil in die digtheid van *O. pes-caprae* tussen verskillende bewerkings-metodes. 'n Post Hoc LSD toets het 'n beduidende verskil in die digtheid van bogrondse *O. pes-caprae* plante tussen kontrole terreine (geen versteuring) vergeleke met persele wat een of ander vorm van grondversteuring ondergaan het aangedui. Daar was egter geen beduidende verskil in die volloophed van *O. pes-caprae* op persele wat een of ander vorm van versteuring ondergaan het (i.e. Skoongemaakte vs Getilde vs Geskottelde vs Geploegde persele) op heuweltjies nie.

Daar was 'n beduidende verskil in die aantal *O. pes-caprae* bolle wat versamel is tussen blokke (op en af van heuweltjies) en beduidende verskille tussen die bewerkings-metodes. Daar was ook 'n beduidende verskil in bol-deursnitte tussen bewerkings-metodes wanneer dit tussen heuweltjie en nie-heuweltjie persele vergelyk is. Die bolle is in vier metingsklasse verdeel. Die grootste aantal klein (2-5 mm deursnit) en medium (5-8 mm deursnit) bolle is in die Getilde bewerkings-metode gevind. In kontras het die Kontrole behandeling (onbewerk) die grootste aantal groot (14-17 mm deursnit) en medium bolle gehad.

Samevattend het *T. sinuata* die potensiaal om gebruik te word in die rehabilitasie van ou lande in kombinasie met die tilling bewerkings-metode. Aandag moet geskenk word aan die effek van *O. pes-caprae*, veral op heuwetjies waar hierdie spesies 'n totale dominansie in die rehabilitasie eksperiment getoon het.

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Chapter one: General Introduction

1.1. Introductory remarks

This thesis focuses on monitoring a rehabilitation trial set up four years ago on an old field in the Worcester Veld Reserve in the Little Karoo region of the Succulent Karoo, South Africa. Seven indigenous species were reseeded in 2001, of which only four species germinated and survived to the present. These surviving species are *Pteronia incana* (Burm) DC., *Tripteris sinuata* DC., *Ehrharta calycina* SM and *Chaetobromus dregeanus* Nees. Five different cultivation methods were used to enhance germination rates. The number of seedlings that survived differs according to the cultivation methods and soil type. Seedling survival was used as an indicator of persistence in harsh climates and to compare different cultivation methods in the rehabilitation process. Further objectives of the thesis were to study the impact of *Oxalis pes-caprae* on species diversity in a restored old field, and to record its ability to disperse in old fields under variable cultivation methods.

The structure of this thesis is as follows: Chapter 1 deals with the literature review of rehabilitation, while also providing an overview of the Succulent Karoo. Chapter 2 deals with the monitoring of the rehabilitation trials and the potential impact of *O. pes-caprae* in these different trials. Chapter 3 supplies general conclusions on rehabilitation in semi-arid areas, and proposes further research possibilities for rehabilitation in the Succulent Karoo.

1.2. Thesis rationale

During the past 100 years concerns over degradation in the Karoo have had a major impact on the development of an agricultural policy for South Africa (Hoffman *et al.*, 1999). Natural veld is one of southern Africa's major natural resources (Witbooi, 2002) and overgrazing and improper agricultural activities have resulted in an overall decrease in the productivity of this valuable commodity.

Land degradation has been defined in different ways but a more comprehensive definition describes it as "the aggregate diminution of the productive potential of the natural resource, its farming systems and its value as an economic resource" (Stocking and Murnaghan, 2001). Human related factors are responsible for the accelerated forms of land degradation. The most frequently recognized human causes of land degradation include overgrazing of rangelands, over cultivation of croplands and deforestation (Stocking and Murnaghan, 2001).

Rehabilitation is of key importance, especially in arid zones where there has been substantial evidence of degradation. This is especially so in the Karoo region of South Africa, where degradation due to grazing (Hoffman *et al.*, 1999), mining (Milton, 2001) and mismatch of agricultural practices (Milton *et al.*, 1994) has resulted in a critical need for an understanding of the best rehabilitation practices to follow under specific conditions.

Ecosystems will continue to degrade under pressure of increased demands unless we apply preventative and rehabilitation strategies to achieve sustainable and healthy ecosystems. Vegetation composition can be changed by clearing existing vegetation, altering the availability of nutrients and water or by sowing seeds of less abundant species. Employing such techniques to re-establish indigenous forage species could possibly increase the carrying capacity and plant species diversity of abandoned fields (Milton *et al.*, 1994).

The objective of rehabilitation of old-fields is to bring back the natural vegetation and to increase the productivity of the land by reseeding palatable indigenous species. Generally reseeding or transplanting indigenous species can facilitate the succession process and increase the species diversity, which can lead to a stable plant community. In the Little Karoo approximately 90 000 ha of old fields are unutilised (Witbooi, 2002). Depending only on a natural succession process to restore unutilised old fields would mean that the period of recovery would be longer than the life span of an average farmer. Human intervention is required to facilitate the process of rehabilitation of old-fields. Therefore a project was initiated in 2000 to study the potential of selected Karoo species for rehabilitation of old fields with an integration of mechanical cultivation to facilitate seed germination and seedling survival. After three years there was a need to monitor and evaluate the reseeded indigenous species and integrate this information with outcomes of mechanical cultivation to make a recommendation for best practice that enhance the productivity of the land.

A secondary focus of this thesis was to understand how a particular indigenous plant species, *Oxalis pes-caprae*, influences the rehabilitation process on old fields in the Little Karoo. *Oxalis pes-caprae* is an invasive alien plant in many parts of the world, especially in Mediterranean climate zones (Peirce 1997). Although *O. pes-caprae* is indigenous to southern Africa, it invades disturbed land, especially along roadsides and vineyards (Ornduff 1987). This study therefore focuses on the extent to which *O. pes-caprae* influences the rehabilitation process in the semi-arid Succulent Karoo.

1.3. Rehabilitation in semi arid areas

Rehabilitation is defined as the return of an ecosystem to a close approximation of its condition prior to disturbance. In rehabilitation, ecological damage to the resource is repaired through both the structure and function of the ecosystem. Merely recreating the form without the function, or the function in an artificial configuration bearing little resemblance to a natural

resource, does not constitute rehabilitation. The goal is to emulate a natural, functioning, self-regulating system that is integrated with the ecological landscape in which it occurs (Natural Research Council, 1992). As ecological rehabilitation is defined, it is a process through which degraded land is returned to a state close to the prior natural condition. Old-fields in semi-arid climates that have been cultivated for long periods are more difficult to rehabilitate to their prior natural condition, due to the change of soil chemistry, texture, infiltration rate and the lack of availability of suitable micro-sites for the seeds of indigenous species to germinate and for seedlings to survive (Geft 1993).

Artificial re-vegetation approaches attempt to compress the process of plant establishment into a single period regardless of our inability to predict the environmental episodes necessary to drive germination and seedling establishment. As a result, many land managers conceptualise re-vegetation of disturbed lands as an instantaneous phenomenon where plants are sown or introduced and rapidly establish to form a permanent static community (Call and Roundy, 1991). This perception is invalid in many disturbed lands in arid and semi-arid areas, where natural or synthetic community development is a long-term, dynamic process that is influenced by factors of disturbance, micro-site heterogeneity, climatic fluctuation and the life history attributes of plant species in the region. Our understanding of the subsequent processes of competition, interaction and stabilization in such systems is still seriously lacking. A better understanding of the relationships among plants is needed in order to re-establish stable, functional communities on disturbed land (Allen, 1988).

Rehabilitation has developed more as a technology than as a science over the past several decades. Most research efforts have been site-specific, short-term and empirical, focusing on the immediate problems of plant establishment and soil stability rather than long-term basic

studies focused on the processes of plant establishment and development of the community (Call and Roundy, 1991).

The major factors affecting the success of rehabilitation in arid environments are limited water availability, loss of biodiversity, loss of topsoil and temperature extremes (Call and Roundy, 1991). Natural re-vegetation tends to be slow and stochastic in arid and semi-arid areas, where water frequently limits or prevents plant establishment and growth (Call and Roundy, 1991).

Rehabilitation of old-fields, particularly in arid and semi-arid regions, is regulated by episodic rather than average environmental conditions. Successful establishment of a species may require the co-occurrence of seed sources, seed placement in favourable micro-sites, adequate precipitation to stimulate germination and recurrent precipitation for seedling establishment. Fluctuations in weather or resource availability may cause substantial annual variation in the productivity of individual species (Noble, 1986).

Plant establishment by seedling recruitment is the dominant type of regeneration for most plants in semi-arid areas. Rehabilitation of indigenous species will be successful when the requirements for seed germination, seedling establishment and subsequent growth are matched with the micro-environmental factors of the seedbed such as soil moisture and soil physical and chemical characteristics. However, seedling recruitment for the rehabilitation of disturbed areas is a result of the number of seeds landing in favourable micro-sites or "safe sites" in the seedbed, rather than the total number of available seeds (Harper *et al.*, 1965). Seeds of most species germinate best when buried at a proper depth in a firm seedbed.

Species sown in mixtures for rehabilitation in semi-arid areas should be chosen based on sound ecological evidence that they can coexist. Unfortunately, research that provides this evidence is still lacking and will be needed in the future (Pyke and Archer 1991). The selection of the seven indigenous species for the rehabilitation trial in the Worcester Veld Reserve was based only on the palatability of the plants and their ability to germinate in open areas (Witbooi, 2002). Successful coexistence in many cases will depend on morphological or physiological attributes. These enable various species at key stages in their life cycle to partition site resources effectively in space and time. Seed mixtures that contain species with distinctly superior competitive and/or establishment ability produce stands with species abundance relationships different from what would be predicted from the proportions of seed sown of each species (Schuman *et al.*, 1982).

1.4. Introducing the Karoo

The Karoo is situated in the arid and semi-arid south-western region of South Africa. It occupies about 35% (427 000 km²) of the land surface of South Africa and is a geologically, climatically and floristically diverse region (Cowling, 1986). The Karoo flora contains an astounding variety of growth forms and its plants range widely in size and shape, type and degree of succulence, leaf consistency and longevity, thorniness, woodiness and below ground structures (Midgley and van der Heyden, 1999). Structurally, Karoo vegetation can be characterized as an open dwarf shrubland. The vegetation is overwhelmingly dominated by members of the Aizoaceae, Asteraceae, Asclepiadaceae, Asphodelaceae, Fabaceae, Iridaceae, Mesembryanthemaceae, Poaceae and Scrophulariaceae (Cowling, 1986). It has been divided into two distinct biomes based on climatic variables and life form spectra; namely the Nama and Succulent Karoo biomes (Rutherford and Westfall, 1986). This study mainly focuses on a monitoring the success of an old-field rehabilitation trial and the effect of *O. pes-caprae* in the Succulent Karoo (Figure 1).

The Succulent Karoo biome occupies 4.3% of South Africa's land surface (Rutherford and Westfall, 1986). It is a very species-rich region, with high levels of diversity at all scales (Cowling *et al.*, 1989). It includes *ca.* 730 genera of which 67% are endemic to the biome. Another unusual feature of the flora is the high species to genus ratio of 6:9 (Cowling and Hilton-Taylor, 1999).

The entire Succulent Karoo receives its rainfall from weather systems associated with disturbances of the westerly wave. The westerly waves are associated with disturbances in the westerly air stream. To the rear of the surface trough, cloud and accompanied precipitation occur in unstable air; ahead of the trough, stable air ensures clear, fine weather (Desmet and Cowling, 1999). The Succulent Karoo is primarily distinguished by the presence of low but predictable winter rainfall and extreme summer aridity. Rainfall varies between 20 - 290 mm per year. During summer, temperatures in excess of 40°C are common (Low and Rebelo, 1995).

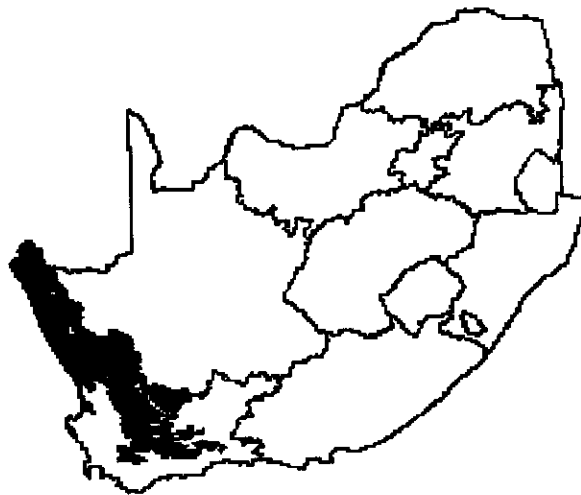


Figure 1. Biogeographical range of Succulent Karoo biome (From Low and Rebelo, 1995).

In arid to semi-arid regions soil forms are important controls of the abundance and distribution of plants and animals, as has been demonstrated in the Karoo (Watkeys,

1999). The lack of moisture in arid regions results in less weathering and leaching when compared to humid regions, so that large areas of bare rock may be present and very old soils are preserved. The slow soil formation results in shallow, coarse soils with sharp boundaries, causing the soil to be very sensitive to degradation (Watkeys, 1999).

Semi-arid soils are high in most plant nutrients, but generally poor in nitrogen and with low water infiltration due to the low organic matter content (Ellis and Lambrechts, 1998). Ants and termites collect organic matter in patches or contribute to the movement of organic matter underground, thereby influencing the local distribution of moisture and plant nutrients in the soil (Palmer *et al.*, 1999). Mima-like mounds, known locally as heuweltjies, are characteristic of the Succulent Karoo. Heuweltjies, which occur at a density of 2.05 ± 0.13 per ha⁻¹, are higher in organic matter, nutrients and salt concentrations (Milton 1992) than the surrounding vegetation. The soils are generally well supplied with most of the important plant nutrients and these have an influence on vegetation patterns (Lovegrove 1993).

1.4.1. Degradation of vegetation in the Karoo

Over the past century degradation of the Karoo has had a major impact on the development of an agricultural policy for South Africa. Different agricultural initiatives have been implemented, such as stock reduction schemes, privatization of communal lands, the initiation of a national grazing strategy and incentives for small grain growers (Hoffman *et al.*, 1999). All of these initiatives have highlighted degradation and changing plant composition, which has led to decreased stock grazing potential. Coupled with this have been a hostile economic environment and a decline in productivity and profitability of intensive small grain cultivation on marginal lands. Many of these farms are now abandoned and no longer used for agricultural activities (Hoffman *et al.*, 1999).

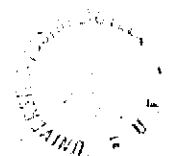
It is generally believed that it has been the mismatch of agricultural land use practices with the production potential of the land that has led to wide-spread desertification in arid and semi-arid South Africa (Milton *et al.*, 1994). More than 80% of land in the Karoo belongs to private owners where extensive sheep and goat, and to a lesser extent, cattle farming on natural rangeland remains the major agricultural practice (Hoffman *et al.*, 1999).

Clearing of natural vegetation and intensive ploughing for agricultural activities creates a fragmented landscape with patches of natural vegetation. This influences seed dispersal, the movement of pollinators across the fragmented landscape of natural vegetation and impacts on soil chemistry, soil properties and soil compaction. Natural succession in semi-arid areas is an extremely slow process. Limited by soil moisture, semi-arid areas cannot economically support intensive and costly re-vegetation practices. Re-seeding or transplanting of indigenous species are potential tools for old field improvement in terms land recovery (Snyman 2003).

1.4.2. Invasive plants in the Karoo biome

Some alien plants have been established in the Karoo since the late Stone Age period (Deacon, 1986), but none of these early natural colonizers have become particularly dominant or problematic. Disturbance caused by newly settled farmers and their livestock created conditions that favoured the establishment of alien plants. These predominantly included non woody shrubs and annual herbaceous species such as *Argemone ochroleuca* Sweet and *Salsola kali* G (Milton *et al.*, 1999).

The situation worsened with time, because the settlers began to introduce trees and shrubs to recreate a home environment. They planted species that would provide fodder, shade, fuel and protection. Many of the species they selected exhibit features that characterize



aggressive invaders, namely copious seed production, efficient dispersal mechanisms, tolerance to drought and the ability to coppice or reproduce vegetatively. Some of the introduced species thrived in the new environment and soon escaped into the natural vegetation (Milton *et al.*, 1999). In semi arid environments plants must either tolerate or avoid drought through short life spans and reliance on soil-stored seed banks or bulbs. Drought avoidance appears to be more frequent among introduced species than drought tolerance (Milton *et al.*, 1999). The three main factors contributing to the growth rate of an invader plant are resources, natural enemies and the physical environment, all of which vary in time and space. How a species responds to these factors, including their spatial and temporal variation, determines its ability to invade (Davis *et al.*, 2000).

Localised soil disturbance and amelioration by ants or termites (Dean and Yeaton, 1993) and selective grazing of such sites by livestock probably generate the patch distributions of alien grasses observed in Namaqualand and the Little Karoo (Vlok, 1994). There are also several species native to the Karoo, which have become important invaders in other regions and continents with similar climatic and edaphic conditions. Some of these species are *Galenia africana* L., *Acacia karroo* Hayne, *Ehrharta calycina* Sm and *O. pes-caprae* L. (Milton *et al.* 1999).

The present study mainly focused on *Oxalis pes-caprae* and its potential to invade old fields in response to different magnitudes of disturbance. This indigenous species is an invader in old fields in the succulent Karoo and elsewhere in South Africa and the world. In various countries, including Australia and the United States of America, it is considered to be a serious invader (Peirce 1997). This species is most often associated with Mediterranean climates, but also occurs in subtropical and semi-arid regions (Peirce 1997). In Mediterranean regions, *Oxalis pes-caprae* is invasive in Italy, Greece, Spain, and the Iberian Peninsula, as

well as in North Africa (Damanakis & Markaki 1990). In Australia, it has invaded widely throughout the cooler regions, and has become a serious weed in all states and territories. It is often seen in disturbed areas and can occur in all soil types. It tends to do best on heavy, well drained, fertile soils, especially in cultivated fields (Peirce 1997). *Oxalis pes-caprae* is native to southern Africa (Salter 1944). It is distributed from Namibia southward to the Cape region and around the Indian Ocean coastline at least as far as east of Knysna (Ornduff, 1987). Even though it is indigenous to South Africa, it has the potential to invade disturbed agricultural fields such as vineyards and roadsides (Ornduff 1987).

1.4.3. Rehabilitation in the Succulent Karoo

Different conceptual ideas such as the deterministic (Yeaton and Esler, 1990) and stochastic (Westoby *et al.*, 1989) models have been developed to understand vegetation dynamics in arid and semi-arid rangelands. The stochastic model proposes that unpredictable climatic or disturbance factors can change vegetation from one state to another in terms of structure or species composition in natural vegetation (Westoby *et al.*, 1989). Predicting the success of re-vegetation of an old field in the Succulent Karoo could be influenced by unpredictable climate and the enduring changes to soil chemistry, particularly that of elevated salinity, which appears to prevent recovery. Other changes in soil chemistry such as an increased nutrient status and pH also change the vegetation composition (Perkins and Thomas, 1993).

The rates of post disturbance recovery of the vegetation of ploughed and cleared sites under arid conditions are extremely slow (Dean and Milton, 1995). When monitoring the recovery of restored land, one has to distinguish between short-term fluctuations, gradual succession type changes and more or less permanent changes in vegetation state. In the

more arid part of the Karoo, post disturbance recovery is less rapid despite the availability of species of all successional stages in the vicinity (Dean and Milton, 1995).

There are five main factors that can potentially slow down the natural succession of an old-field in semi-arid regions:

- Inadequate supply of indigenous seeds due to intensive ploughing in the past and the resulting landscape fragmentation (Milton and Dean 1990).
- High densities of herbaceous plants, which are pioneers in most disturbed old-fields and are short-lived, producing many seeds for the next generation. These compete for light, water and nutrients, often preventing the establishment of later successional species (Milton 1994).
- A reduction in vegetation cover and a reduced abundance of micro-sites that trap wind-blown seed (e.g. dead succulents, litter-trains or mammal diggings) (Yeaton and Esler, 1990; Hoffman and Cowling, 1987), reducing the probability of seeds germinating on the site.
- Habitat change as a result of ploughing, which results in altered soil properties for example loss of micro-symbionts (Schlesinger *et al.*, 1990) and compaction of soil, which reduces water infiltration (Van der Merwe and Kellner, 1998).
- Many Karoo plants germinate and survive under nurse plants. Since old fields are generally bare, newly germinated plants will be directly exposed to sun, frost and wind. This may also delay the recovery from ephemeral to perennial vegetation (Beukman 1991).

Some form of soil disturbance or active restoration is usually necessary to break the impenetrable crusts and the compaction layer that prevent the effective establishment of plants. Although sandy soils do not compact, there is still some crust formation on bare sandy soils that negatively affects the germination of seed (Van der Merwe and Kellner, 1998).

Rangeland managers have applied a variety of mechanical treatments over the long and short-term to restore veld in several areas of South Africa, the object being to prevent the development or increase of bare patches (Van der Merwe and Kellner, 1998) and to enhance seed germination. Very few attempts have been made on the rehabilitation of old-fields. Past rehabilitation attempts are also often difficult to interpret due to the lack of proper experimental design and are difficult to obtain because they have not been published in the primary literature (Witbooi 2002).

Partial clearing of the existing vegetation and sowing seeds of less abundant species, especially of palatable plants, can change vegetation composition. Applying cultivation methods and sowing mixed seed of different species to re-establish indigenous forage species could possibly increase the carrying capacity and species diversity in old-fields (Milton and Hoffman 1995). Three beneficial changes in soil properties could be brought about by cultivation. These are increased infiltration rates, increased water availability and better root growth. Improvement in soil permeability achieved by sub-soiling is particularly important in clay soils and can be as crucial in rehabilitation of old-fields as it is for arable cropping (Van der Merwe and Kellner, 1998).

1.5. Summary of the rehabilitation trial of 2002

A rehabilitation trial on the Worcester Veld Reserve was initiated to investigate some of the problems and solutions that farmers face in implementing rehabilitation processes on old lands. The rehabilitation trial was conducted by Witbooi between 2000-2001 on an old field in the Succulent Karoo. In this study, five land preparation techniques and the reseeded of seven indigenous species were applied. The aim of the study was to investigate a) the importance of the soil stored seed bank in the rehabilitation of old lands, b) the role of propagule migration in species composition of these disturbed area, c) the requirements for

species composition of these disturbed areas and d) the effect of different re-vegetation techniques on species establishment.

The seven indigenous species selected were perennial plants, selected on the basis of their palatability and ability to germinate in open areas. They were: *Tripteris sinuata* DC. (Asteraceae), *Ruschia spinosa* L. Bol. (Aizoaceae), *Drosanthemum speciosum* (Haw.) Schwantes (Aizoaceae), *Indigofera sessifolia* DC. (Fabaceae), *Ehrharta calycina* Thunb. (Poaceae), *Chaetobromus dregeanus* Nees. (Poaceae) and *Pteronia incana* Burm (Asteraceae).

The results from the trial, 1 - 2 years after initiation, showed that the correlation between perennial canopy cover of old-fields and the soil seed bank is low, and that seed banks are dominated by disturbance adapted species, mostly *O. pes-caprae* (bulbs) and *Atriplex semibaccata* on heuweltjies sites. The ability of a species to re-appear could be dependent on its ability to persist in the soil seed bank (Bakker *et al.*, 1996). After disturbances on off-heuweltjie sites, *Athanasia trifurca* was the most dominant perennial plant. Seed bank experiment results indicated that the existing seed bank had little value in the rehabilitation of old fields (Witbooi, 2002). Therefore active rehabilitation attempts must be made to increase the productivity of the land.

Only four of the seven reseeded indigenous species germinated and survived. These were *T. sinuata*, *C. dregeanus*, *E. calycina* and *P. incana*. The species with the highest germination rate was *T. sinuata*, followed by *E. calycina*, *C. dregeanus* and *P. incana*. The germination percentage of the four species differed between cultivation methods. Germination of *C. dregeanus* was higher on ploughed plots than on tilled, disked, control or cleared plots. *Tripteris sinuata* germinated better on tilled plots than on plots subjected to the other four

cultivation methods. *Pteronia incana* had the lowest germination rate on most of the plots. Based on seedling persistence over one year on the rehabilitation trial, *T. sinuata* performed best, followed by *C. calycina* and *C. dregeanus*. *Pteronia incana* failed to persist. There was no difference in seedling survival between localities i.e. on- and off-heuweltjies in the first two years. Therefore monitoring the rehabilitation trial of the old field after three year was initiated to evaluate the performance of reseeded indigenous plant species and mechanical cultivation methods used to enhance the germination and survival of seedlings. The results of Witbooi, 2002) shows some evidence that the population numbers of *Oxalis* species increases with an increase in the intensity of disturbance, but this was never tested scientifically. Soil disturbance creates conducive environments for invaders to germinate and compete for resources. The vegetative reproduction of *Oxalis* taxa may be an important mechanism for dispersal on disturbed old fields.

1.6. Concluding remarks

Abandoned lands in arid lands (old fields) are generally agricultural fields used for crop production then abandoned due to various reasons, for example low profitability due to the marginal nature of the climate. Abandoned farmland has experienced at least two changeovers, first when its natural vegetation was removed to create farmland, then again when agricultural crops were no longer cultivated. Now a land in between, abandoned farmland is neither wilderness nor cultivated, and is often in need of rehabilitation and recovery to some semblance of natural conditions, frequently through human intervention.

Natural re-vegetation tends to be slow and stochastic on arid and semi-arid rangelands, where germination and survival of seedlings are influenced by erratic rainfall, temperature extremes and edaphic factors. This makes it difficult to pin point a single reason to explain why induced changes cannot be reversed naturally. Extreme and active efforts are required to restore an old-field back to a state of natural vegetation comparable to conditions prior to

the disturbance. In order to develop a rehabilitation strategy and techniques for old-fields in semi-arid and arid regions one needs to understand the vegetation dynamics, soil properties and ecosystem function of the region.

For restoration in semi-arid areas it is also necessary to understand the life history of keystone species in terms of their germination, growth, phenology and interaction with other species. Neither reseeding/transplanting nor cultivation alone will lead to rapid changes in vegetation composition. Therefore human intervention in the rehabilitation of old-fields is needed to facilitate the germination of seedlings, increase species diversity and improve the succession process of the ecosystem and ultimately to increase the productivity of the land.

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Chapter II

Monitoring the success of an old-field rehabilitation trial in the winter rainfall Succulent Karoo: the effect of *Oxalis pes-caprae*

Abstract

A rehabilitation trial was initiated in 2000 that targeted potential of selected Karoo species for rehabilitation of an old field in the Worcester–Robertson Karoo of the Western Cape Province, South Africa. Seven indigenous species were reseeded into an old field and different cultivation methods were applied. The performance of these species and the method of cultivation used was assessed in 2003. Of the seven-reseeded species only four germinated in 2000 and persisted until September 2003. These were *Tripteris sinuata* DC., *Chaetobromus dregeanus* Nees, *Ehrharta calycina* SM and *Pteronia incana* (Burm.) DC. The highest number of seedlings that survived on heuweltjies were those of *T. sinuata*. Survival of this species was consistently higher than that of the other three species that germinated. This species has potential to be used for the rehabilitation of old fields to increase the productivity of land as rangelands in the Succulent Karoo. There was also a significant influence of cultivation methods on the survival and establishment of seedlings. The Tilled cultivation method resulted in the highest number of surviving seedlings both on and off-heuweltjie sites.

Witbooi (2002) found that the indigenous *Oxalis pes-caprae* was a potential weed in old fields. This indigenous weedy species increases its population size with an increase in the magnitude of soil disturbance. The density of *O. pes-caprae* was significantly different between on and off-heuweltjie sites. The above ground plants increase with the intensity of disturbance especially on heuweltjies. The number of *O. pes-caprae* bulbs increased with the magnitude of soil disturbance on and off-heuweltjies. There were also significant differences between cultivation methods and the frequency distribution of *O. pes-caprae* bulb sizes found on and off-heuweltjies. There was a direct relationship between density of above ground and the number of under ground bulbs on off-heuweltjie blocks.

2.1. Introduction

The importance of human intervention on rehabilitation of old fields is to increase productivity and biodiversity of previously unproductive areas. In most countries humans have dramatically altered and diminished ecosystems by mismanagement and overexploitation (Aronson *et al.*, 1993). Coupled with climatic change, these actions have caused deterioration of an estimated 75% of the productive portion of dry lands. Dry lands in Africa cover 43% of the landmass with about 65% of the countries classified as dry land (UNSO/UNDP, 1997).

Rehabilitation of arid and semi-arid lands has become increasingly important in many countries (Stocking and Murnaghan, 2001). Old fields have been assumed to be capable of recovery without intervention. This may be true in more humid environments where abandoned land is usually colonized rapidly by plants (Horn, 1974), but in arid and semi-arid environments recruitment is not necessarily rapid due to the unpredictable nature of the environment. Water availability is generally considered to be the single most limiting resource for plant growth (Boyer 1985), particularly in arid and semi-arid environments because rainfall is low, highly variable and inherently unpredictable (Allen 1991).

A rehabilitation trial was initiated by Witbooi (2002) between 2000-2001 to select potential indigenous species for rehabilitation of old fields in Succulent Karoo. Different cultivation methods were used to facilitate the germination and survival of target species. The basic building blocks for rehabilitation of degraded abandoned land are soil seed banks and favourable soil conditions, both of which are often lacking due to intensive ploughing. This study was initiated to monitor the performance of the reseeded indigenous plant species and to evaluate the mechanical cultivation in terms of seedling survival on unprofitable

abandoned farmlands. Extensive abandoned agricultural lands in the Succulent Karoo biome have not been subjected to the same level of environmental regulation as land damaged by mining.

Furthermore invasive plants are a major problem and a growing concern in areas that have been designated for rehabilitation of native plant communities (Luken and Thieret 1997; McKnight 1993). Witbooi (2002) showed that *Oxalis pes-caprae* is a potential invader on disturbed old-fields in the Succulent Karoo. She showed that *O. pes-caprae* increased in terms of number of plants with different magnitudes of disturbance. Even though *O. pes-caprae* is indigenous to South Africa, it invades disturbed areas along roadsides and in vineyards (Kluge and Claassens 1990). In other parts of the world (U.S.A., Australia and several Mediterranean countries) *O. pes-caprae* invades natural vegetation (Peirce 1997). A second objective of this study is to understand the effect of *O. pes-caprae* on the reseeded indigenous species in rehabilitation trials of an old field in the Succulent Karoo.

A significant task for conservation biologists is to assess and monitor species richness in fragmented habitats, to design appropriate action plans to preserve whatever biodiversity is left and to rehabilitate degraded areas (Cousins and Lindborg 2004). Monitoring is regarded as an essential part of any rehabilitation plan for degraded areas. The objective of monitoring is to be able to follow the progress of ecosystem development so that failures can be recognized and quickly corrected and success parameters deduced.

2.2. Objectives of the study

Witbooi (2002) conducted a rehabilitation trial between 2000-2001 on an old field in the Succulent Karoo. Her aim was to investigate the potential of selected indigenous plants to establish under different cultivation methods. Seven species were reseeded and five cultivation methods were applied with different magnitudes of disturbance. Witbooi's

(2002) objectives were to test the effects of these cultivation methods on the seed bank, seedling germination and seedling survival on the old fields. The main objective of the present study was to monitor the success of the rehabilitation trial and make recommendations as to effective methods of rehabilitation. The second objective was based on the result of Witbooi 2002 that showed there was a tendency of *O. pes-caprae* to invade disturbed old lands. In the study by Witbooi (2002), there was some evidence that the number of *Oxalis* species increased with disturbance, but this was never tested further. Thus a second objective was to test if *O. pes-caprae* impacts species diversity and the potential success of rehabilitation attempts on old fields. Two of the key questions listed below focus on understanding the spread of *O. pes-caprae*, while the remaining key questions aim to assess the successes of indigenous species in restoring an old field.

Key questions:

- To what extent has the rehabilitation trial set up by Witbooi (2002) been a success as measured by the abundance of established plants of the indigenous species that she used to reseed the old field?
- Is it possible, three years later, to evaluate the various treatments set up by Witbooi (2002), and if so, can recommendations on appropriate cultivation techniques be made?
- Does the abundance of *O. pes-caprae* increase with an increase in intensity of prior disturbance?
- Can we explain the variation in abundance of *Oxalis* species present on the different sites in terms of bulb morphology and reproductive strategy?

2.3. Material and methods

2.3.1. Study site

The study site was in the Worcester Veld Reserve (33°39' S, 19°26' E) situated in the Worcester–Robertson Karoo area of the Western Cape Province, South Africa. The Worcester Veld Reserve is situated on a ridge of Malmesbury shale in the Breede River valley and is surrounded by quartzite mountains of the Table Mountain Group (Witbooi 2002).

The long term mean annual rainfall (1935-1998 years) of the study site is 242.7 mm (Worcester Veld Reserve) and falls mainly from June to August. The lowest mean monthly temperature of 7.4 °C occurs in July and the highest mean monthly temperature of 34.5 °C occurs in January (Stokes 1994). Rainfall varies between 20—290 mm per year. During summer, temperatures in excess of 40°C are common (Desmet and Cowling 1999).

The vegetation of this area is classified as a succulent form of Karroid Broken Veld (Low and Rebelo 1995). The vegetation of the area is typically sparse dwarf shrubland and is included in the Succulent Karoo Biome (Rutherford and Westfall 1994). A wide range of growth forms exists in the region. The soils are skeletal and derived from Malmesbury shale, but soils on the heuweltjies are richer in nutrients, more moist than surrounding soils and alkaline (Stokes 1994). Soils are poorly drained, shallow and weakly developed, but can attain a depth of two meters or more in valley bottoms and alluvial plains (Scott and Van Breda 1938).

The actual site was previously utilized for introducing species for the production forage seeds which would be suitable for use in veld reinforcement in the Little Karoo region. It has been an old field for ± 15 years, and during this period the area was periodically brush cut for no

other reason than to keep it tidy. This was done prior to the rehabilitation trial by Witbooi (2002).

2.3.2. Species selection

Seven species indigenous to the Succulent Karoo were reseeded in 2000 as part of the rehabilitation trial. These were *Tripteris sinuata* DC. (Asteraceae), *Ruschia spinosa* L. Bol. (Aizoaceae), *Drosanthemum speciosum* Haw. (Aizoaceae), *Indigofera sessifolia* DC. (Fabaceae), *Ehrharta calycina* Thunb. (Poaceae), *Chaetobromus dregeanus* Nees. (Poaceae) and *Pteronia incana* Burm. (Asteraceae). Only four of these species survived until September 2003. The species selected to monitor the success of the rehabilitation trial was based on the results of Witbooi (2002) and field observations in 2003. The highest numbers of surviving seedlings out of the four species that successfully germinated in 2000 were those of *T. sinuata*. This species also survived on and off-heuweltjies sites; therefore it was selected as indicator to investigate which cultivation method is more appropriate to use in the rehabilitation of old-fields. The number of surviving seedlings of the other three indigenous species that germinated in 2000 was very low, thus only qualitative information is presented for them.

Oxalis pes-caprae (L.) was selected for closer study as Witbooi (2002) indicated that it has the potential to influence the success of the rehabilitation of old fields.

2.3.2.1. *Tripteris sinuata*

Tripteris sinuata belongs to the family Asteraceae and is commonly known as Bietou. It occurs in the winter rainfall region from Cape Point in the Western Cape Province to the Richtersveld in the Northern Cape Province. It is fairly common in the Ceres Karoo and in the Little Karoo it extends to Uniondale. It is a perennial dwarf shrub that can reach a height of 500 mm and a diameter of about 1 m. The leaves are arranged oppositely and are

about 30 mm long and 8 mm wide. Both the ray and the disc flowers are yellow. They are borne in terminal heads with a diameter of about 25 mm. The ripe fruitlets are pale brown and winged (Shearing and Van Heerden 1994). *Tripteris sinuata* has very well-developed root systems and lateral roots can spread as far as 5 m around the plant. It is highly palatable and is preferentially grazed by domestic livestock and wild mammals, most probably because of its high protein content and low concentration of secondary compounds (Milton 1992).

2.3.2.2. *Oxalis pes-caprae*

Oxalis pes-caprae (sorrel) belongs to the family Oxalidaceae. The genus name is derived from the Greek words for acid and salt, referring to the sour-tasting oxalic acid present throughout the plant. *Oxalis pes-caprae* is native to the Western Cape Region of South Africa (Salter 1944) and it is a stemless (or short-stemmed) perennial herb (Salter 1944). The specific epithet *pes-caprae* means goat's foot, perhaps referring to the clover/cloven shape of the leaves. Bermuda buttercup is the common name most frequently used in the United States of America, and refers to its yellow-flowers and likeness to the buttercup family. In Australia *O. pes-caprae* is commonly known as soursob in reference to its sour taste (<http://tncweeds.ucdavis.edu/alert/alrtoxal.html>).

Shoots of *O. pes-caprae* arise from a short vertical subterranean stem (rhizome) that is attached to a pale brown underground bulb. The trifoliate (clover-like) leaves arise from an enlarged basal stem tip, and are arranged in a loose basal rosette. Petioles are usually less than 120 mm long. The leaflets are often spotted and display hairy abaxial surfaces (Hickman 1993).

Flowers of *O. pes-caprae* are bright yellow and are arranged in umbellate inflorescences. Sepals of *O. pes-caprae* are green, lanceolate to oblong in shape, and the tips often have

two orange or yellow calli. The yellow petals are clawed and each flower has 10 stamens (Salter 1944).

Oxalis pes-caprae has a strong potential to spread vegetatively and easily colonizes disturbed areas. The vertical subterranean rhizome has nodes and internodes, and tiny bulbils are continually formed in the node axils. In undisturbed soil these bulbils eventually break free from the parental plant, and give rise to new clonal plants directly adjacent to the parent. In disturbed areas the bulbils can be spread over considerable distances and give rise to dense clonal stands of this species. Thus an individual plant is capable of producing 10-40 bulbils in a favourable climate each year (Galil 1968; Villà and Gimeno 2004).

2.3.3. Plot design

A randomised complete block design was applied by Witbooi (2000) to five treatments (cultivation methods) on both on and off-heuweltjie sites in 2000. The main rehabilitation site consisted of 7, 15 m x 25 m plots, each subdivided into 5 plots (15 x 5 m²) within which 5 subplots (3 x 5 m²) were located to avoid edge effects (Figure 2). Two of the seven blocks are located on heuweltjies, while 5 of the blocks were located off-heuweltjies. The cultivation treatments were control, cleared, tilled, disked and ploughed.

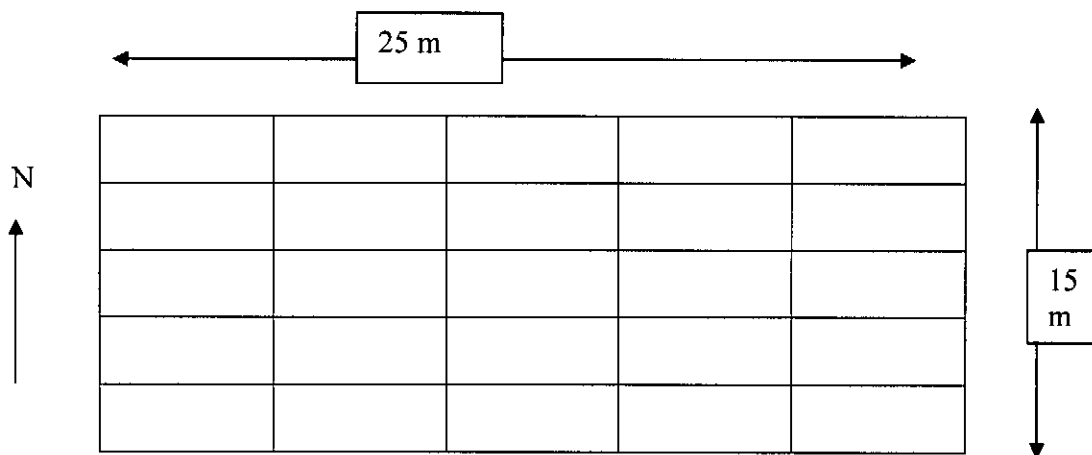


Figure 2. Randomised complete block plot design. One block consists of five mechanical treatments and five seed treatments. The size of plots was $3 \times 5 \text{ m}^2$ and block size, $15 \times 25 \text{ m}^2$.

2.3.4. Sampling techniques

2.3.4.1. Vegetation

To monitor success of the rehabilitation trial, plant cover abundance and number of *T. sinuata* seedlings in each treatment were recorded in one plot of $3 \times 5 \text{ m}^2$ in each treatment.

The data from July 2001 and September 2003 were used to compare the effectiveness of different cultivation methods and the influence of soil disturbance on seedling survival. The number of individual *O. pes-caprae* plants was counted twice, once at the beginning of July and again at the end of September 2003. The plot used to count number of *O. pes-caprae* was in one-meter square permanent plots within each treatment and both on and off-heuweltjies. In addition, presence of additional species on each plot was recorded.

2.3.4.2. Soil sampling

Soil samples were collected from all blocks both on and off-heuweltjies sites at the end of September 2003. Soil samples were collected with the aid of a semi-automatic auger. Five random soil cores (200 mm deep and 70 mm in diameter) were collected from each treatment so that a total of 175 soil samples was collected. The soil was then sieved and *O. pes-caprae* bulbs were collected, counted and measured. The diameter of bulbs was measured in mm using an Electronic Calliper.

2.4. Data analysis

The number of *O. pes-caprae* plants counted within one-meter square, the number of bulbs and their size distribution in all treatments were compared using two-way ANOVA. Data were Log (10) transformed when needed to fulfil the assumptions of the ANOVA, which was carried out according to a randomised complete block design. Multiple comparisons within the ANOVAs were done using Post Hoc tests. Comparisons between two variables such as number of seedlings that survived between two different years and cover abundance between on and off-heuweltjie sites were done using a student T-test. All statistics were performed using the statistical software Systat 6.1.

2.5. Results

2.5.1. Monitoring the success of the rehabilitation trial

2.5.1.1. Seedling survival

Seven species were initially reseeded in the rehabilitation trial of 2000. Only four species were recorded as established in the year immediately following the establishment of the trial; these were *T. sinuata*, *C. dregeanus*, *E. calycina* and *P. incana*. The highest level of

recruitment in 2001 was recorded for *T. sinuata* followed by *P. incana*, *E. calycina* and *C. dregeanus* (Witbooi 2002).

In September 2003, three years after the trial was initiated, seedling survivorship was again estimated in order monitor to the success of the rehabilitation trial. The plants were identified in the plot by its permanent tag done in 2001. The highest number of seedlings counted was for *T. sinuata* followed by *E. calycina*, *C. dregeanus* and *P. incana*. *Triptaris sinuata* was selected to analyse the effect of various cultivation methods on the success of rehabilitating old fields, because it had the highest number of surviving seedlings in all cultivation methods, both on and off-heuweltjies. *Ehretaria calycina* and *C. dregeanus* survived mostly under ploughed cultivation treatment which have deeper furrow than the other three species.

The total number of *T. sinuata* seedlings that survived on and off-heuweltjie sites until September 2003 was 242, a proportionally high percentage (77%) of the 297 seedlings that were recorded in July 2001 (Figure 3). Survival of *T. sinuata* seedlings on heuweltjie versus off-heuweltjie sites was significantly different. In July 2001 the number of seedlings surviving on heuweltjies sites was 29 (3X5 m² area) and in September 2003, only 13-seedlings were left, which was 46% of the original seedlings. On the other hand the number of *T. sinuata* seedlings that survived in off-heuweltjie sites until September 2003 was 213, which is 71% of the original number of seedlings.

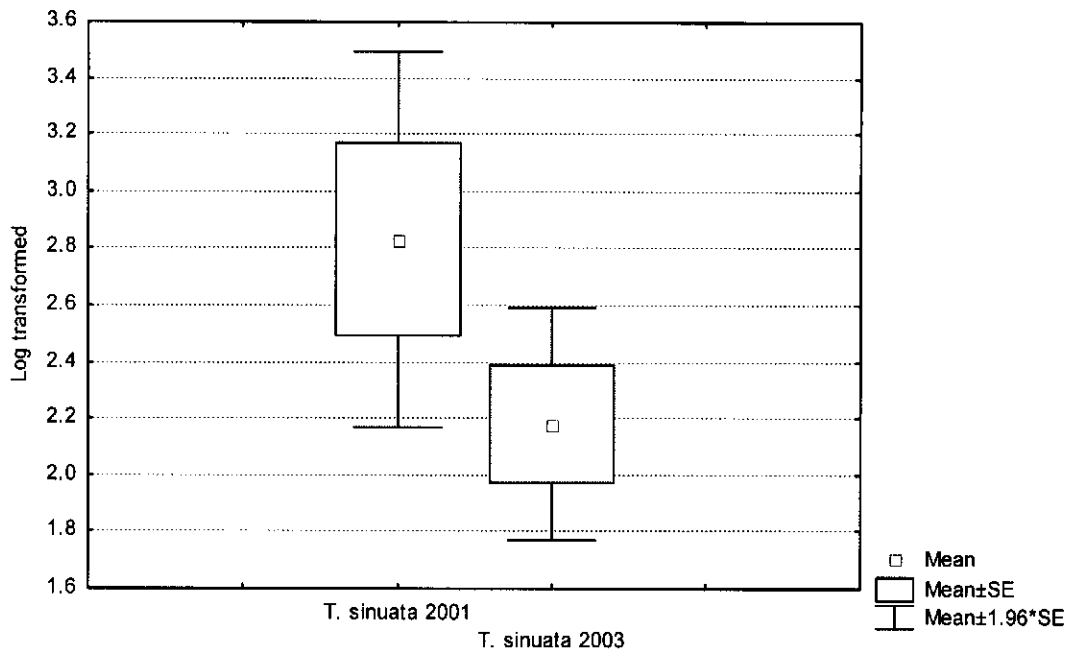


Figure 3. The overall number of *T. sinuata* seedlings recorded in combined on and off-heuweltjie sites in 2001 and 2003.

Analysis of variance (ANOVA) was done separately for the number of *T. sinuata* seedlings that survived within off-heuweltjie sites. This analysis showed that there is a significant difference ($F_{(6,213)}=P < 0.001$) in the density of seedlings between cultivation methods. The Post-Hoc test (LSD) showed that there is a significant difference ($P < 0.001$) between the Tilled treatment and the three other cultivation methods (Control, Ploughed and Cleared) (Figure 4). Very few *P. incana* seedlings survived from 2001 to 2003, only about 20% of the total number of 65 seedlings. The low numbers meant that no analysis could be done to compare the response of this species to cultivation methods. *Ehrharta calycina* and *C. dregeaus* seedlings also survived in low numbers overall, but most survived only along the deeper furrow ridges on Ploughed sites.

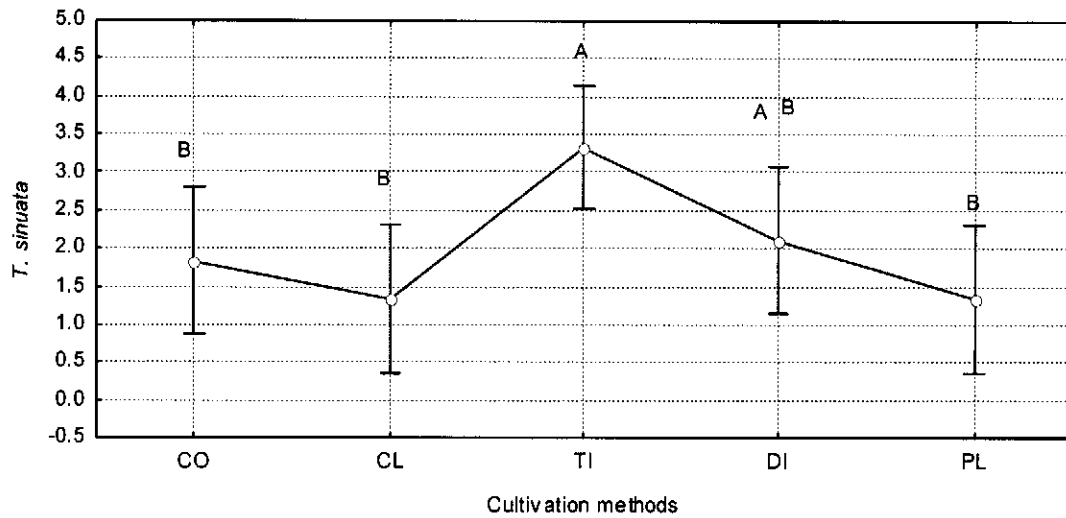


Figure 4. Average number of *T. sinuata* seedlings that survived until September 2003 on off-heuweltjie sites. Co= Control, CL= Cleared, Ti= Tilled, DI= Disked and PL= Ploughed.

2.5.1.2. Succession of species on the rehabilitation site

The plant composition of perennial plants increased significantly since 2001 especially in off-heuweltjie sites where there was a 26% increase in plant cover (Figure 5). Visual observations of canopy size on off-heuweltjie blocks 3 and 4 were different from the rest of the blocks. The change in plant composition on on-heuweltjie sites was not as noticeable, since they remained dominated mostly by annual species and some perennial plants adapted to disturbance. The most abundant species were *O. pes-caprae*, followed by *Atriplex semibacatta* R. Br, *Salsola kali* L. and *Galenia africana* L. (Plate 1).

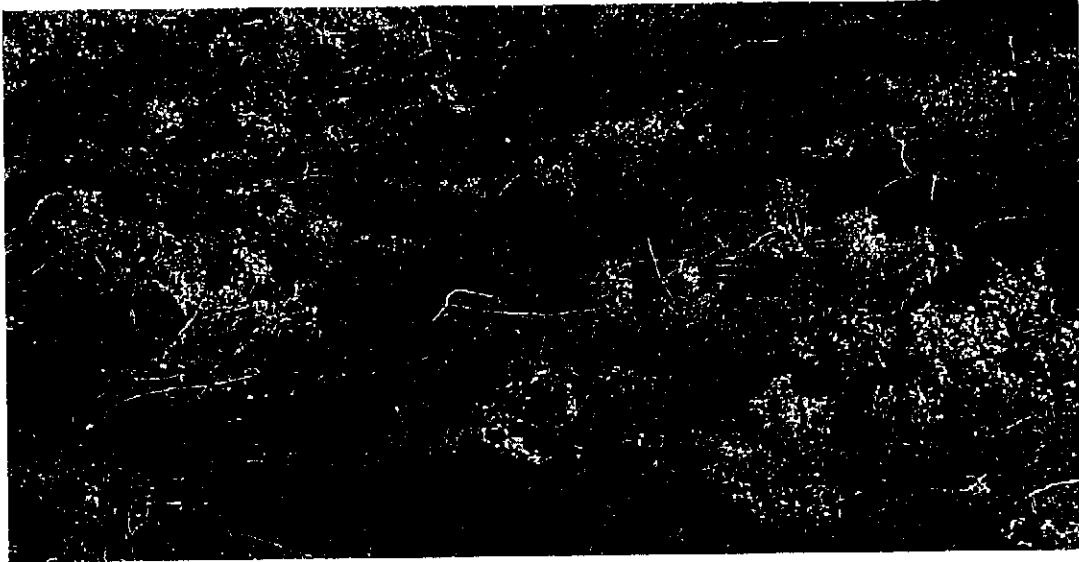


Plate 1. Dominance of *O. pes-caprae* (bright green) on heuweltjie sites along with other disturbance-adapted species.

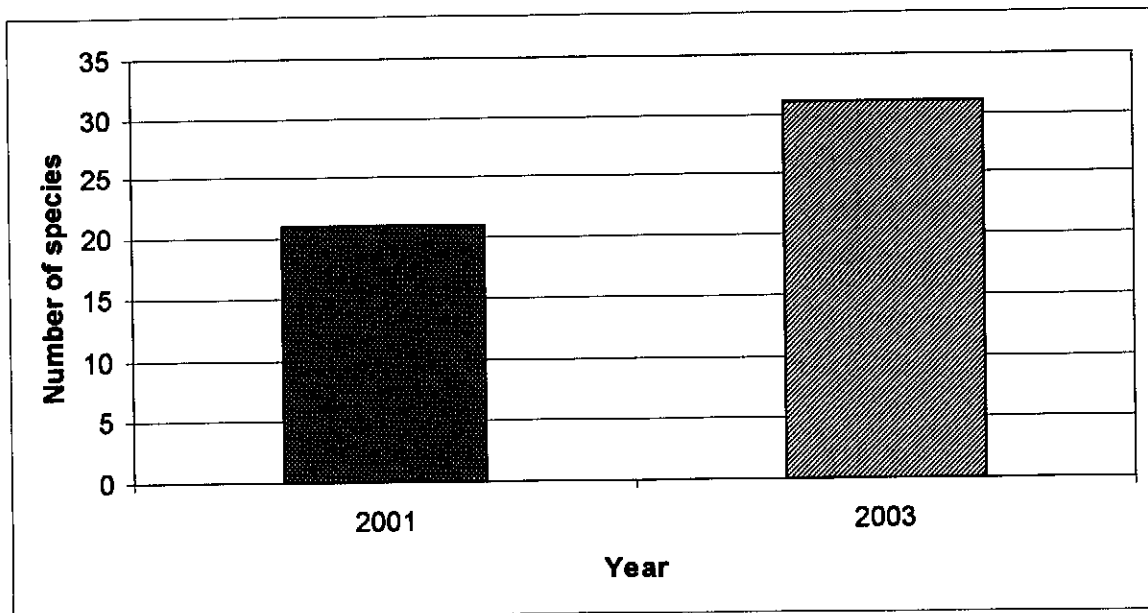


Figure 5. The number of species found on off-heuweltjie sites (3x15 m²) during 2001 and 2003.

A significantly ($P < 0.05$) greater number of species was recorded in 2003 compared to 2001 in off-heuweltjie sites (Figure 5, Table 1). Species were those mostly adapted to disturbance (Table 1).

Table 1. List of common plant species found on off-heuweltjie sites during 2001 and 2003

Species	2001	2003	Life form
<i>Albuca</i> sp.	X	X	Perennial
<i>Athanasia trifurca</i> L.	X	X	Perennial
<i>Atriplex semibaccata</i> R. Br.		X	Perennial
<i>Atriplex vestita</i> Thunb	X	X	Perennial
<i>Cf Ehrharta</i>	X	X	Perennial
<i>Cf. Eriocephalus africanus</i> L.	X	X	Perennial
<i>Chaetobromus dregeanus</i> Nees.	X	X	Perennial
<i>Chrysocoma ciliata</i> L.	X	X	Perennial
<i>Cynodon dactylon</i> (L.) Pers.		X	Perennial
<i>Dimorphotheca tragus</i> (Aiton) B. Nord		X	Perennial
<i>Drosanthemum hispidum</i> (L.) Schwant.	X	X	Perennial
<i>Drosanthemum</i> sp.		X	Perennial
<i>Echium plantagineum</i> L	X	X	Biennial
<i>Elytropappus rhinocerotis</i> L.f.	X	X	Perennial
<i>Felicia macrorrhiza</i> Thunb.	X	X	Perennial
<i>Galenia africana</i> L.	X	X	Perennial
<i>Helichrysum cf. asperum</i> Thunb.	X	X	Perennial
<i>Helichrysum</i> sp.	X	X	Annuals/perennial
<i>Heliophila</i> sp.		X	Annuals/perennial
<i>Lepidium</i> sp.	X	X	Annuals/perennial
<i>Mesembryanthum guerichianum</i> Pax		X	Perennial
<i>Plantago lanceolata</i> L.	X	X	Perennial
<i>Prekia pallens</i> Ait	X	X	Perennial
<i>Ruschia multiflora</i> Haw.	X	X	Perennial

<i>Rushia cymosa</i> (L. Bol.) Schwnat.	X	X	Perennial
<i>Salvia</i> sp.		X	Annuals/perennial
<i>Sutherlandia microphylla</i> Burch. Ex DC.	X	X	Perennial
<i>Tetragonia sarophylla</i> Fenzl.		X	Perennial
<i>Tripteris oppositifolia</i> Less.		X	Perennial

2.5.2. Above-ground presence of *O. pes-caprae*

The density of above ground plants of *O. pes-caprae* (number of plants per one-meter square) in all plots was compared to determine if there was any correlation with the degree of soil disturbance, the assumption being that disturbance enhances the spread of this species due to the way that it propagates. The data were tested for normality using a Kolmogorov Smirnov (K-S) test ($P < 0.001$) and transformed using Log (10) in order to obtain a normal distribution.

The multivariate ANOVA results showed that there was a significant difference ($F_{(6,116)} = P < 0.001$) in the density of above ground plants between blocks (Table 2). The Post-hoc LSD test showed that there was also a significant difference ($P < 0.001$) between off-heuweltjie sites 2, 4 and 6 (off-heuwe 2, off-heuwe 4, and off-heuwe 6) and off-heuweltjie site 1. There is also significant difference in the density of the above ground plant between heuweltjie (sites 1 and 2) with all plots off-heuweltjie sites (Figure 6). The Post Hoc LSD showed clearly that there is also a significant difference in the density above ground plant ($P < 0.001$) between on and off-heuweltjie sites (Figure 6).

Table 2. Results of an ANOVA test for the number of above ground *O. pes-caprae* individuals on and off-heuweltjies. Culti. = Cultivated, SS = sum of square, D.F. = Degree of freedom, MS = Mean of square, F value and P = the probability

	SS	D.f.	MS	F	P
Intercept	712.37	1	712.37	7348.789	0.000000
Blocks	20.23	6	3.3724	34.790	0.000000
Culti.Method	1.87	4	0.4691	4.839	0.001027
Error	15.89	164	0.0969		

The ANOVA test showed that there is a significant difference ($F_{(4,116)}=P< 0.001$) between cultivation methods (Table 2). The Post Hoc LSD test showed a significant difference ($P< 0.001$) in the density of above-ground *O. pes-caprae* plants between control sites (no disturbance) compared to those sites that underwent some sort of soil disturbance. There was, however, no significant difference in the abundance of *O. pes-caprae* on plots that underwent some sort of disturbance (i.e Cleared vs Tilled vs Disked vs Ploughed sites) (Figure 7).

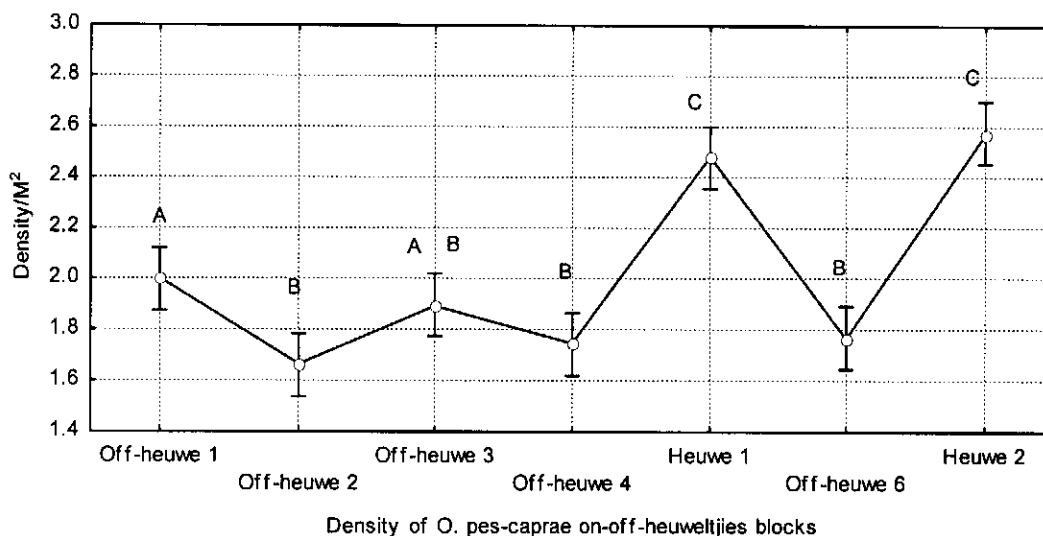


Figure 6. Density of above ground (number per m^2) *O. pes-caprae* on and off-heuveltjies. Off-heuwe = off-heuveltjie and Heuwe= Heuveltjie blocks. The same letter symbols (A, B or C) indicate that they are not significantly different to each other. Error bars are centred at the mean and extend one standard deviation on both sides.

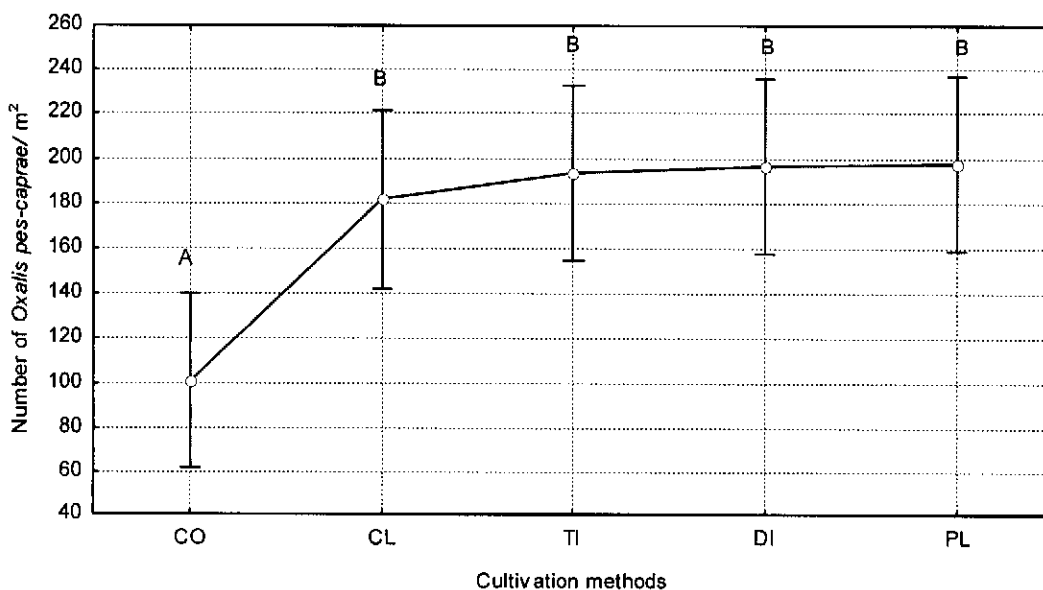


Figure 7. Density (number per 1 m^2) of above ground *O. pes-caprae* plants occurring in plots that underwent various cultivation treatments. Having the same letter (A or B) means that the cultivation methods are not significant to each other. Error bars are centred at the mean and extend one standard deviation on both sides. Co= Control, CL= Cleared, Ti= Tilled, DI= Disked and PL= Ploughed.

When the density of the above ground plants of *O. pes-caprae* was analysed separately for off-heuweltjie blocks only, the analysis of variance (ANOVA) showed that there was a significant difference ($F_{(4,116)}=P < 0.001$) between blocks and cultivation methods (treatment) (Table 3).

Table 3. ANOVA test for the density of above ground (number per m²) of *O. pes-caprae* off-heuweltjies. (SS sum of square, D.F. Degree of freedom, MS Mean of square, F value and P the probability)

	SS	DF	MS	F	P
Intercept	412.4098	1	412.40	6899.410	0.000000
Block	1.6244	4	0.4061	6.794	0.000060
Cultivation methods	2.4547	4	0.6137	10.266	0.000000
Error	6.9339	116	0.0598		

The Post Hoc Scheffe Tests for the off-heuweltjie blocks showed a significant difference in density of *O. pes-caprae* ($F_{(5,125)}=P<0.001$) individuals between off-heuweltjie block 2 and off-heuweltjie block 1 (Figure 8). The Post-Hoc Scheffe test for Cultivation methods off-heuweltjies showed that there is a significant difference ($F_{(5, 125)}= P <0.001$) between Control sites (no disturbance) compared to those sites that underwent some sort of disturbance (i.e Cleared vs Tilled vs Disked vs Ploughed sites) (Figure 9).

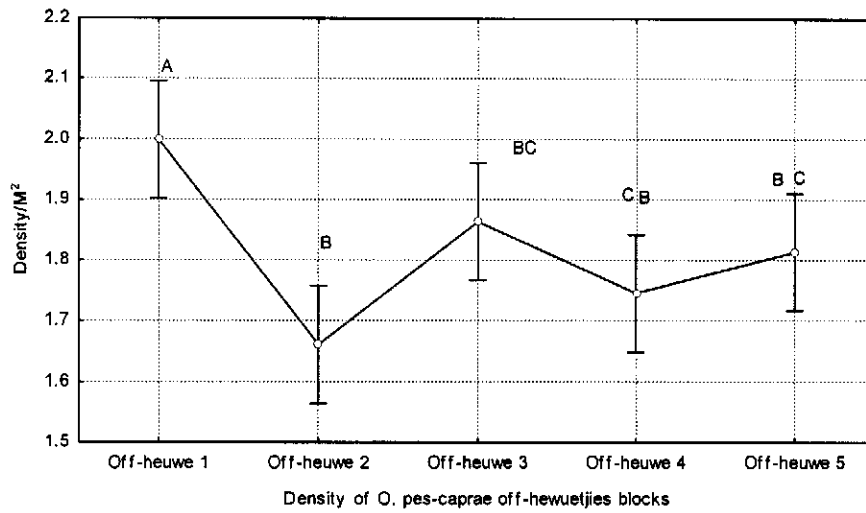


Figure 8. Density (number per m^2) of above-ground *O. pes-caprae* plants off-heuweltjies. Off-heuwe= off-heuweltjie blocks. Having the same letter (A, B or C) indicates that density of above ground plants is not significantly different to each other. Error bars are centred at the mean and extend one standard deviation on both sides.

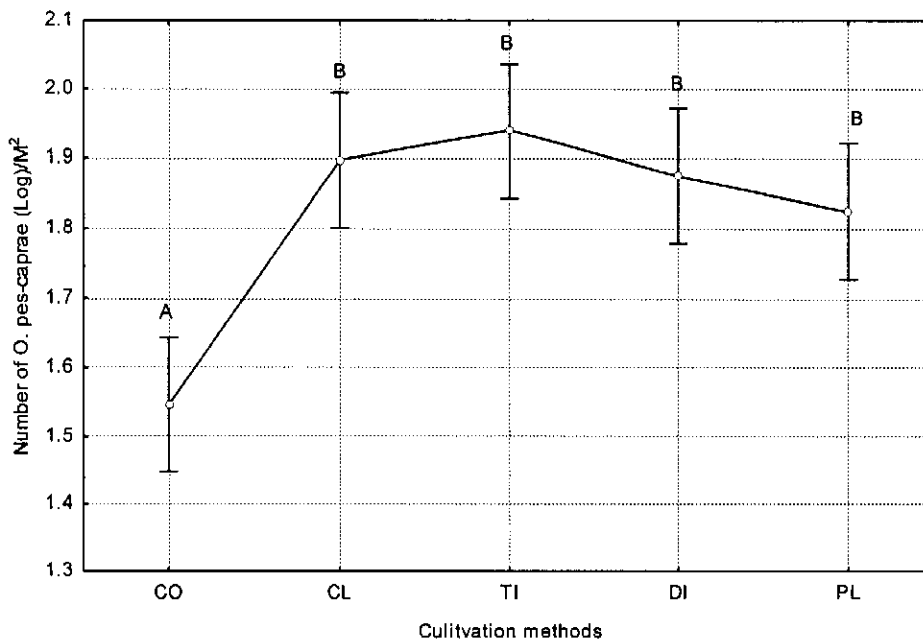


Figure 9. Density above ground (number per m^2) of *O. pes-caprae* in off-heuweltjie sites. Having the same letter (A, B and C) indicates that samples are not significantly different to each other. Error bars are centred at the mean and extend one standard deviation on both sides. Co= Controlled, CL= Cleared, Ti= Tilled, DI= Disked and PL= Ploughed.

A comparison of the above-ground plant density of *O. pes-caprae* between 2001 and 2003 using a T-test showed a significant difference ($P < 0.05$). *O. pes-caprae* was more abundant in 2001 than in 2003 (Table 4) with the magnitude of difference ranging from 40-70% (Table 4).

Table 4. Density of the above-ground individuals of *O. pes-caprae* counted in 1 m² in 2001 and 2003

Treatment	2001	2003	Decrease %
Control	784	225	71
Cleared	837	418	50
Tilled	2003	580	71
Disked	1356	529	60
Ploughed	880	532	39
Ann. rainfall (mm)	282.8	190.5	67

The annual rainfall of 2001 was 282.8 (mm), which is 32% greater than in 2003 (190.9 mm) (Figure 11 & 12). In 2001 the amount of rainfall received from May to October was 253.4 (mm), which is 49% more than the amount of rainfall obtained in 2003 (128.1 mm). The amount and distribution of rainfall within season could have a major effect on germination and survival of seedlings.

The relationship between the number of above-ground plants and number of bulbs was tested. The regression equation was $Y = 0.977 X + 0.339$ and R square was 45.5, indicating a slight positive correlation (Figure 10).

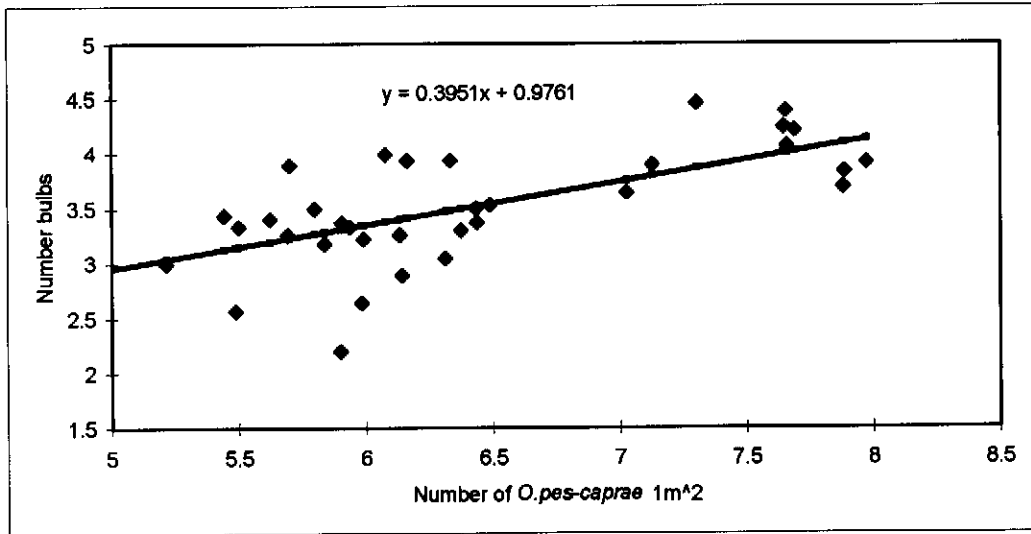


Figure 10. The relationship between the density of above ground plants and the number of bulbs of *O. pes-caprae*.

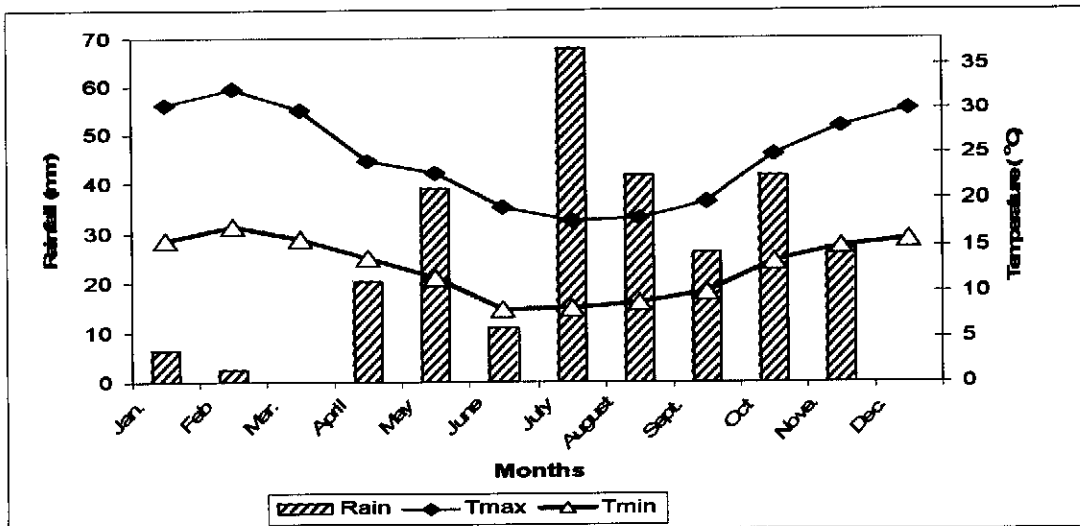


Figure 11. Monthly rainfall (mm) and monthly average temperatures for 2001 as measured in the Worcester Veld Reserve. Source: South African Weather Service Stellenbosch CSIR (Climate Division).

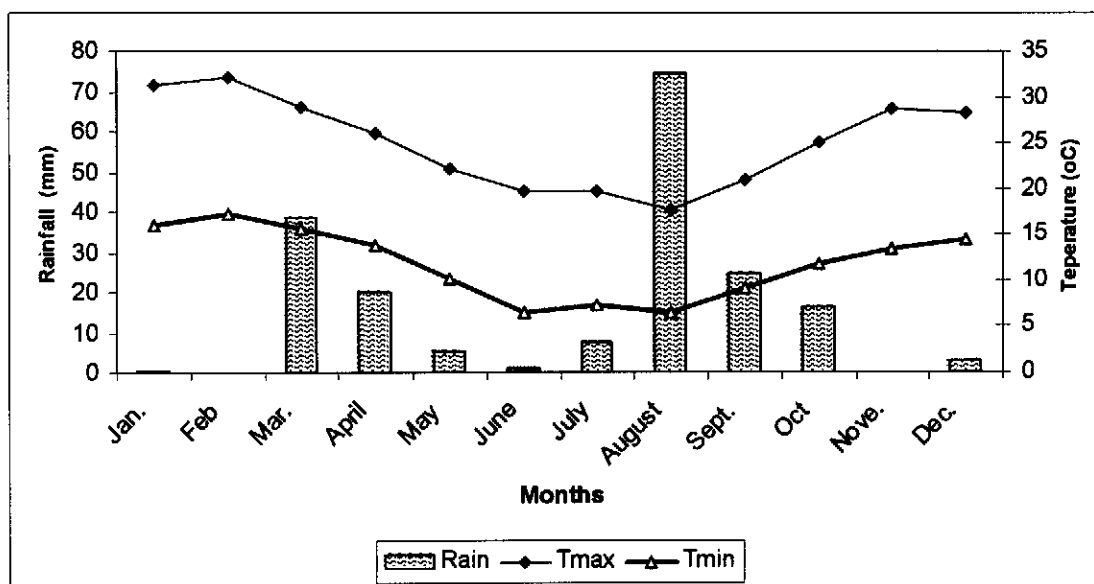


Figure 12. Monthly rainfall (mm) and monthly average temperatures for 2003 as measured in the Worcester Veld Reserve. Source: South African Weather Service Stellenbosch CSIR (Climate Division).

2.5.3. Below-ground presence of *O. pes-caprae*

An analysis of variance shows that there is a significant difference ($F_{(6,322)} = P < 0.001$) in the number of *O. pes-caprae* bulbs collected between blocks (on and off-heuweltjie) and also significant differences in number of bulbs ($F_{(4,322)} = P < 0.05$) between cultivation methods (Table 5).

Table 5. Analysis of variance for number of *O. pes-caprae* bulbs collected in the Worcester Veld Reserve in 2003

	SS	DF	MS	F	P
Intercept	52380.46	1	52380.46	491.3081	0.000000
Block	7555.54	6	1259.26	11.8113	0.000004
Cultivation method	1409.26	4	352.31	3.3046	0.027202
Error	2558.74	24	106.61		

The Post Hoc test (LSD) shows that there was a significant difference in the number of bulbs between off-heuweltjie blocks 2 (off-heuwe 2) versus off-heuweltjie blocks 3 and 4 (off-heuwe 3 and 4) (Figure 13). The Post Hoc test (LSD) also showed clear differences in the number of bulbs collected between blocks on and off-heuweltjie sites (Figure 13). The Post Hoc (LSD) for the number of bulbs compared within the different cultivation methods showed that there was a significant difference ($P < 0.001$) between Tilled cultivation and the other three cultivation treatments (Control, Disked and Ploughed) (Figure 14).

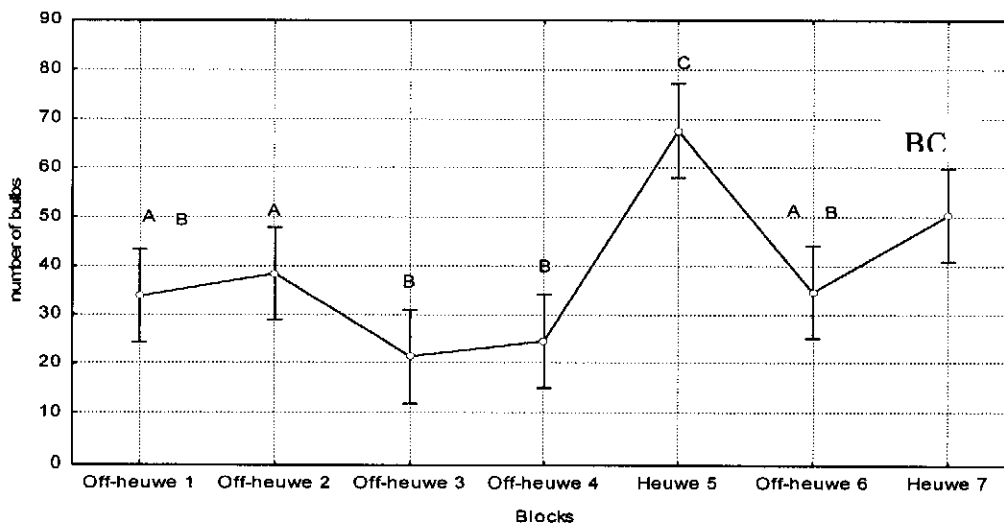


Figure 13. Number of bulbs on both on and off-heuweltjies sites. Having the same letter A, B or C mean the blocks are not significantly different ($P < 0.05$). Error bars are centered at the mean and extend one standard deviation on both sides. Off-heuwe = off heuweltjie sites; Heuwe = on heuweltjie sites.

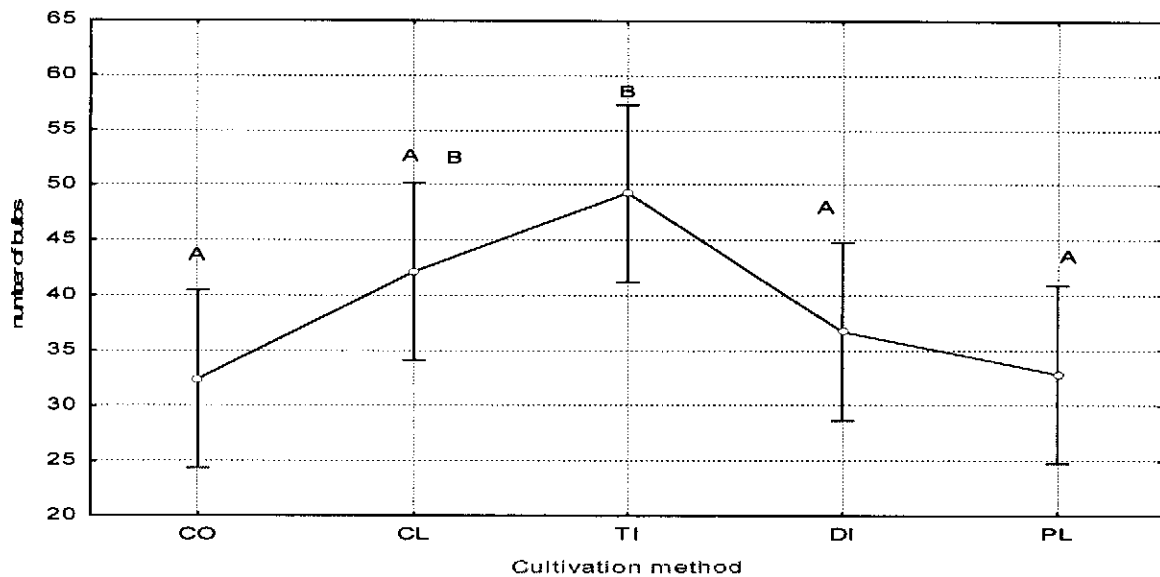


Figure 14. Number of bulbs on all sites (combined on-off heuweltjies sites). Having the same letter A, B or C means that they are not significant ($P < 0.05$) to each other. Error bars are centered at the mean and extend one standard deviation on both sides. Co = Controlled, CL = Cleared, Ti = Tilled, DI = Disked and PL = Ploughed.

2.5.4. Bulb diameter

The bulbs were classified into five classes according to their diameters. ANOVA results showed that there was a significant difference ($F_{(4,322)} = P < 0.001$) in bulb diameter between blocks and cultivation methods off heuweltjies (Table 6). Three hundred and thirty four bulbs were collected from heuweltjie sites compared with 55 bulbs collected from off-heuweltjie sites (Figure 15). The highest number of small diameter (2-5 mm) and medium diameter (5-8 mm) sized bulbs were found in the Tilled cultivation method (Figure 16). There were many more bulbs of these to size classes than on the Disked and Ploughed sites. In contrast the Control treatment (uncultivated) had most bulbs in the medium (8-11 mm) and second most in the large (11.1-14 mm) bulb size classes. A few oversized bulbs (larger than 14 mm) were also documented from the control sites, but they were restricted to this treatment, and so few in number that they were omitted from the analysis. The highest number of small and medium size class diameter bulbs were found in heuweltjie sites compared to the off heuweltjie sites (Figure 17).

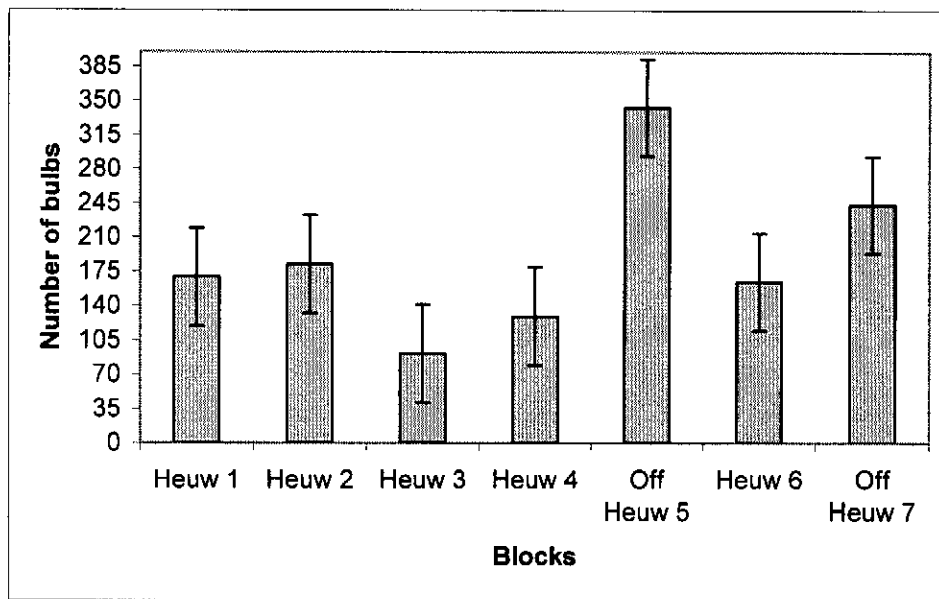


Figure 15. The total number of bulbs collected on and off heuweltjies block. Heuw = Heuweltjies and Off Heuw = Off heuweltjies.

Table 6. Analysis of variance of bulb diameters off heuweltjies

	SS	DF	MS	F	p
Intercept	715.3853	1	715.3853	33650.52	0.000000
BLOCK	2.2121	6	0.3687	17.34	0.000000
Treatment	0.0924	4	0.0231	1.09	0.001560
Error	28.5725	1344	0.0213		

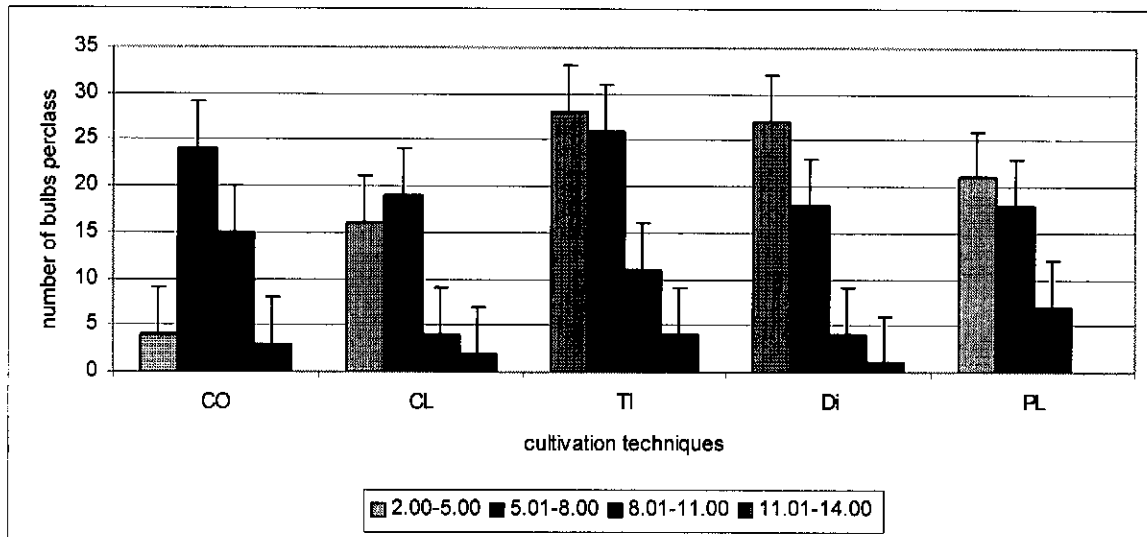


Figure 16. Size class distribution of *O. pes-caprae* bulbs in soils that received different cultivation treatments on an old field in the Worcester Veld Reserve. CO= Control, CL= Cleared, Ti= Tilled, Di= Disked and PL= Ploughed. Size classes are based on bulb diameters and measured in millimeters. The range of size class determined by number of bulbs and size of smallest and largest diameter.

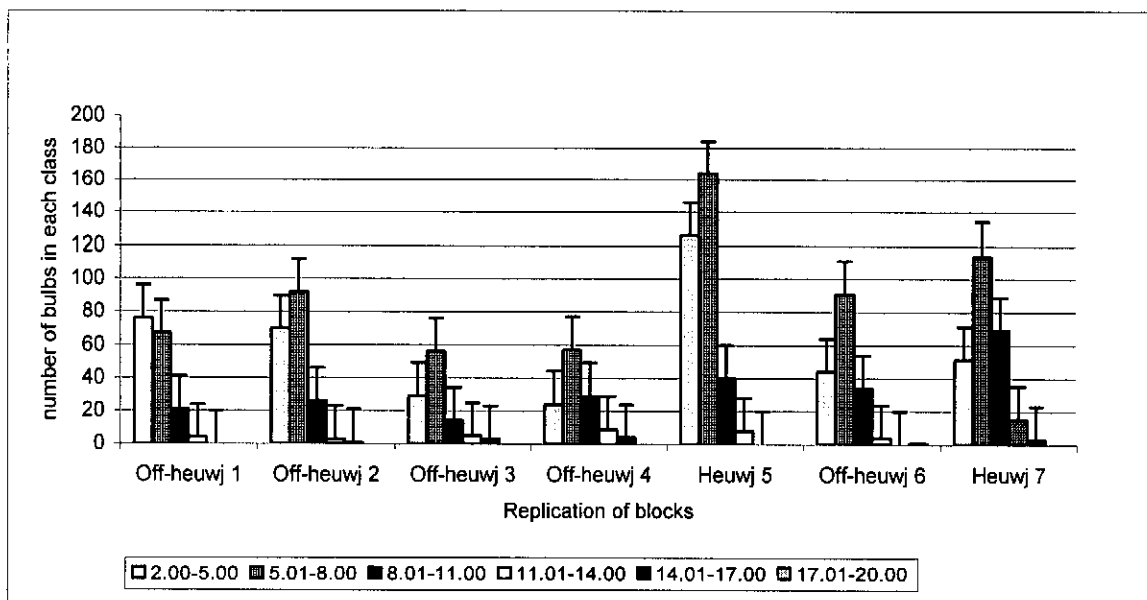


Figure 17. Size class distribution of *O. pes-caprae* bulbs in heuweltjie and off-heuweltjie sites in the Worcester Veld Reserve. Off-heuwj = off heuweltjies blocks and Heuwj = Heuweltjies. Size classes are based on bulb diameters measured in millimetres. The range of size class determined by number of bulbs and size of lowest and largest diameter.

2.6. Discussion

Seedlings of grass species *E. calycina* and *C. dregeanus* survived mostly under Ploughed cultivation methods in deeper furrow ridges both on and off-heuweltjie sites. In other studies, *C. dregeanus* was found to be most successful in the re-establishment of bare patches in the Nama Karoo (Visser *et al.* 2004). Asher and Kickert (1973) monitored micro-environments and indicated that depressed sites retained moisture at the surface longer and had more favourable atmospheric and temperature regimes than smooth soil surfaces. Depressions also create more favourable conditions for soil coverage, which is important for the establishment of seeds (i.e., trapping wind blown particles, sloughing of sides of depressions). Plants in arid and semi-arid regions have to cope with a harsh physical environment, but some avoid these conditions by establishing in favourable micro-climates such as near rocks, in crevices and beneath other plants (Call and Roundy, 1991).

Weidman and Cross (2000) stated that rehabilitation of degraded land can be seen as successful when plants established at a density of 5 plants per m². In the rehabilitation trial investigated in the present study, the highest establishment success was recorded on plots that had been exposed to Tilling. Out of the four species germinated in 2000, *T. sinuata* proved to be the most successful species in terms of both germination and survival rates. *Tripteris sinuata* survived in most plots, and showed a current density of 7-16 plants per 5 m². As *T. sinuata* has a very well-developed root system with extensive lateral roots (Van Breda and Barnard 1991), this could have given it an advantage over the other species to survive in harsh the climate. The same result was also obtained in the Nama-Karoo where the number of *T. sinuata* individuals stayed more or less the same in re-established bare patches (Visser *et al.* 2004). Results found by Visser *et al.* (2004) and the present study support the suggestion that *T. sinuata* has the potential to be used successfully for

rehabilitation of old-fields and bare patches. The species can be used for rehabilitation in semi-arid regions, and its palatability helps to increase the productivity of the rangeland.

2.6.1. Plant succession

The concept of succession provides the theoretical basis for rehabilitation. The processes of succession determine the rate and nature of initial revegetation and continue to influence plant community development long after treatments have been implemented (Bazzaz 1983). Plant communities on and off-heuweltjies were influenced by both the intensity of disturbance and the local edaphic factors. The overall plant cover abundance on heuweltjie sites was dominated by *O. pes-caprae* and a few plant species which are adapted to disturbance. The number of plant species found on heuweltjies sites was very few compared to off heuweltjies. This showed that continuous soil disturbance has a direct effect on species diversity.

Primary succession is the initial stage of plant community rehabilitation following a severe disturbance that leaves bare soil. Initial colonizers, known as pioneer species, establish themselves rapidly during the first growing season. *O. pes-caprae* may be considered as a pioneer plant species on old fields. It can provide soil cover and minimize soil erosion. Often plants involved in primary succession are those that can tolerate a wide variety of conditions including the scarcity of water and nutrients. They reproduce rapidly and often spread large quantities of seed using wind or animals as carriers. *Oxalis pes-caprae* bulbs can be spread by small mammals easily in disturbed areas (Galil 1968).

However, successional trajectories after land abandonment under semi-arid conditions are still poorly understood (Bonet 2004). The major constraints to rehabilitation in these areas are scant and unpredictable rain, prolonged dry seasons and heterogeneity of water and nutrient resources (Schlesinger *et al.* 1990). In general the change of plant composition in semi-arid

areas is very slow and this makes it difficult to monitor the success of rehabilitation trials soon after the trial was conducted.

Witbooi (2002) stated that in general the reproductive potential of the majority of species was low to non-existent when measured on heuweltjies. She based this on seedling: adult ratios. This supports the observation that there were almost no structural changes or changes in plant composition between shrubs and annual plants on heuweltjie sites after 3 years.

Allen (1991) pointed out that spatial variability in shrub-dominated arid and semi-arid sites is distinguished by "islands of fertility" characterized by enhanced soil nutrients and organic matter under existing plant canopies relative to areas between plants. In the Succulent Karoo, heuweltjie soils are formed by termites and remain present even after long-term ploughing. In old fields, this variability does not tend to reduce with ploughing and consequently it forms landscape heterogeneity. This may significantly influence the outcomes of rehabilitation attempts. Heuweltjies can also be seen as "islands of fertility" that differ from the surrounding areas in terms of soil nutrients, water infiltration, deposition of organic matter and plant composition (Esler 1993). Differences in plant composition and survival of seedlings were mostly related to the difference on soil properties and soil disturbance between on and off heuweltjies sites.

2.6.2. Invasion of *O. pes-caprae*

From the results of bulb numbers and density of *Oxalis pes-caprae* bulbs obtained, we can deduce that vegetative reproduction is a successful means of dispersal on old fields in the Succulent Karoo, specifically on heuweltjie soils. All South African *Oxalis* species are trimorphic in natural areas, limiting successful fertilization to legitimate out-crossing between different morphs (Weller 1992). Unequal morph ratios may be more common in weedy South African races than non-weedy ones and are likely a consequence of vegetative propagation

that is enhanced by physical disturbances of the habitat during agricultural or road building activities (Ornduff 1987). Over most of its exotic range of distribution *O. pes-caprae* appears to be represented by a sterile, pentaploid short-styled morph. These short morph pentaploids propagate exclusively vegetatively and have become serious weeds invading the natural vegetation in many parts of the world (Ornduff 1987). *O. pes-caprae* spreads vegetatively by orientating the underground rhizome at an angle, thereby allowing the contractile roots to pull the new bulbils sideways (Galil 1967). The rate of dispersal is, however, rather slow, preventing the species to become too weedy in its natural habitat of South Africa.

The number of *O. pes-caprae* plants on heuweltjie sites were significantly higher than on the off-heuweltjies sites. The first possible reason for this is the physical disturbances on heuweltjie soils, mainly caused by termites and small mammals (Plate 2). These disturbances facilitate the dispersal of *O. pes-caprae* bulbs on heuweltjies. In a study done in Israel by Galil (1968) it was found that small mammals were the main dispersers *O. pes-caprae* bulbs. Results obtained in this study agree with the results obtained by Galil (1968) regarding the number of bulbs on heuweltjie sites. In these sites many bulbs were observed on the soil surface, presumably because they were dug out by small mammals.

The high nutrient status and moisture holding capacity of heuweltjies soils could be more favourable for bulb growth than in inter-mound soils. Dean and Yeaton (1993) stated that ant nests in semi-arid areas, such as in the Karoo, provide a nutrient enriched environment for seedlings and mature plants. Spatial and temporal environmental variation plays an important role in the coexistence of species (Shea and Chesson 2002). Disturbances on heuweltjie sites in the Succulent Karoo landscape by small mammals and other disturbances in the form of ploughing provide a spatial niche opportunity for *O. pes-caprae* to maintain or increase its population size.

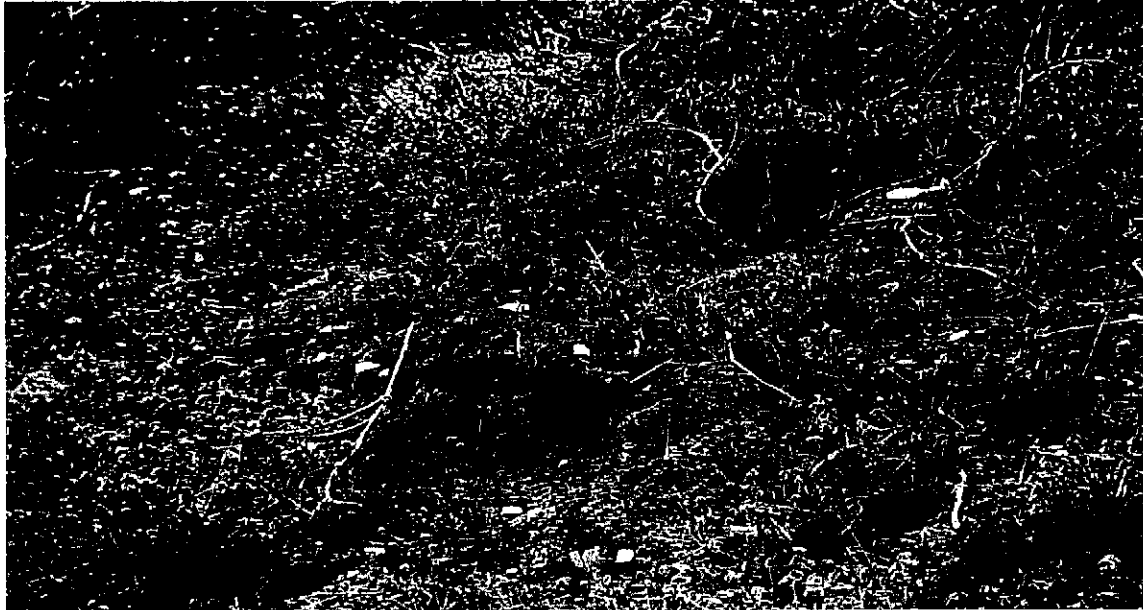


Plate 2. Small mammal diggings as an example of soil disturbances which increase bulb dispersal in heuweltjie sites.

The number of above ground *O. pes-caprae* plants off-heuweltjies increases with the magnitude of disturbance up to a certain limit. The highest number of *O. pes-caprae* individuals was counted in Tilled treatments. This cultivation method always had more *O. pes-caprae* individuals than any of the other four cultivation methods in most of the sites. The number of *O. pes-caprae* plants are limited by stress at the two extremes of disturbance off heuweltjie sites. The Control and ploughed cultivation treatments showed low density of *O. pes-caprae* at the two extremes. The intermediate disturbance hypothesis (Connell 1978) states that intermediate levels of disturbance will lead to the greatest species diversity, but in the old field rehabilitation trial the intermediate disturbance, Tilled cultivation methods show the highest density of *O. pes-caprae* of the four cultivation methods. This is possibly because the Tilled cultivation method increases the amount of moisture infiltration in the soil more than any of the other cultivation methods.

There was a significant difference between 2001 and 2003 in terms of the density of *O. pes-caprae*. More *O. pes-caprae* individuals per 1 m² were found in 2001 than in 2003, ranging from 40-70% more between different cultivation methods. This can be ascribed to two possible reasons. Firstly, the significant difference in density of *O. pes-caprae* between 2001 and 2003 could be the result of the difference in total rainfall received within the growing season (May–October) between these two years. The amount of rainfall was 49% higher in 2001 than in 2003. The reduced rainfall could have significantly influenced the above-ground presence or numbers of *O. pes-caprae*, as all *Oxalis* species are known to sprout and initiate above-ground growth in direct response to rain. It is thus to be expected that the reduced rainfall in 2003 would lead to fewer above-ground plants (Dreyer pers. com.). In addition, this species could perhaps be more commonly found in newly disturbed sites, so that the reduction in numbers in 2003 is due to a longer time since disturbance. As part of a secondary succession process, other plant species could subsequently also have become introduced and established in the plots.

2.6.3. Bulb dispersal

O. pes-caprae is a cosmopolitan weed, which invades many countries with similar agro-climatic conditions to South Africa. This species escaped from gardens and became naturalised in wasteland, riparian vegetation and urban bushland in Australia, U.S.A and some Mediterranean countries (Luken and Thieret 1997). *O. pes-caprae* is predominantly spread through dispersal of its numerous bulbils. We found that the number of bulbils on heuweljies are greater than off-heuweltjies. Without disturbance, the species can spread vegetatively by sending out the underground stem at an angle, thereby allowing the contractile root to pull the new bulbils sideways. Galil (1968) suggests that the number of bulbils produced per plant each year ranges 20-40. If soil is disturbed by small mammals or

land preparation, the bulbs can easily spread to new micro-sites. On Heuweltjie soils there are numerous activities that contribute to the nutrient enrichment of the soil: they are frequently used as dung middens by aardvark (*Orycteropus afer*) and Steenbok (*Raphicerus campestris*), and as colony sites by herbivorous rodents (*Parotomys brantsii*) (Milton and Dean 1990).

In South Africa *O. pes-caprae* shows its potential as weedy plant along roads and vineyards (Ornduff 1987). Its invasion in the Succulent Karoo, specifically in marginal agricultural lands where heuweltjies are present, could have a detrimental effect in terms of productivity and species biodiversity. Heuweltjie soils are regularly spaced, round or oval patches of vegetation that are conspicuously different from the surrounding area (Lovegrove 1993). Disturbance is commonly assumed to release resources and to provide opportunities for invaders, an idea that has been generalized to consider any form of temporal variation in resource availability (Davis *et al.*, 2000). As emphasized by the spatio-temporal resource competition theory (Davis *et al.*, 2000), an invader must have some advantage over residents. However, that advantage might occur at particular times or in particular places or it might be in a life-history trait, such as colonizing ability.

Termite activity results in a raised mound of finer textured, alkaline soil with increased water content and higher water holding capacity. These soil changes favour a different plant community, increasing between patch diversity and providing habitat for other animal species (Palmer *et al.* 1999). Woody shrubs growing in nest mound soils have higher levels of nitrogen than plants growing in inter-mound soils (Dean 1992; Dean and Yeaton 1993). As explained by Palmer *et al.* (1999) nest-mounds of termite species, as well as burrow system of some mammals, also exert an influence on the patch selective grazing which is characteristic of both domestic and indigenous ungulates.

2.7. Conclusion

The condition of abandoned farmland (old fields) in the Succulent Karoo varies depending on the extent to which it was affected by clearing of semi-arid vegetation for farming and for how long it was ploughed. Habitat change, as result of altered soil properties and loss of microsymbionts (Schelsinger et al. 1990), compaction (Bosch and Kellner 1991) and reduced rainfall infiltration (Dean1992) and increase exposure to sun and wind may delay the rehabilitation process of old field. Many Succulent Karoo plant species are dependant on nursing plants under which they grow until they become established (Beukman 1991). Therefore ploughing for agricultural production could remove "nurse plants" and could delay the success of rehabilitation process in Succulent Karoo.

Our results show that the selection of species for reseeding determined the success of rehabilitation of old fields. Only *T. sinuata* has successfully established on the old field, while *E. calycina*, *C. dregeanus* and *P. incana* are still struggling to become established. The cultivation methods used for the rehabilitation of the old field show significant differences in terms of germination and survival of seedlings of reseeded specie. The impact of *O. pes-caprae* on the rehabilitation of old fields was most visible on heuweltjie soils. The density of *O. pes-caprae* individuals increases with an increase in magnitude of the disturbance. This could have a direct effect on species richness, germination and survival of the reseeded species (Plate 1). The number of reseeded seedlings that survived on heuweltjie sites was very low compared to the seedlings that survived on off-heuweltjies sites. *Tripteris sinuata* survival off-heuweltjies was higher than on heuweltjies.

Successful rehabilitation entails re-establishing vegetative characteristics that existed on a site prior to disturbance. Some of these characteristics may be regained over time through natural processes, but highly disturbed landscapes often exhibit the least resilience and may

rely almost entirely on active rehabilitation measures such as soil amendments and revegetation. A full understanding of the dynamics of populations within habitats subject to disturbance requires knowledge of the regime of disturbance and of the subsequent patterns of recolonization and succession in the disturbed patches. Developing effective rehabilitation strategies depends on our ability to predict rates and outcomes of ecosystem recovery via natural processes and to determine how best to intervene to stimulate recovery. However, with few exceptions, only weak predictions of ecosystem recovery can be advanced because the scientific basis for rehabilitation is scant. Consequently, ecosystem rehabilitation is prone to failure. Understanding the dynamics of vegetation within the landscape is therefore very important.

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Chapter III

General Conclusion and Recommendations

This chapter summarizes the main findings of the thesis and makes relatively workable recommendations for the rehabilitation of old fields in the Little Karoo. The objective of this study was to monitor the rehabilitation of an old-field using seedlings of indigenous species and to determine the effect of different cultivation methods on regeneration. Five cultivation methods and seven indigenous species had been used for rehabilitation of old field on and off-heuweltjies sites in 2001. Only four species germinated and survived in the harsh climate of the Succulent Karoo. These four species were used in the final analysis to make recommendations on establishment of indigenous species and the effect of different cultivation methods on germination and establishment.

A further aim was to assess the above and below-ground status of the indigenous weed, *Oxalis pes-caprae*, in this old field rehabilitation trial, with the following questions in mind:

- Does the abundance of *O. pes-caprae* increase with an increase in intensity of prior disturbance?
- Does this trend hold true for any other *Oxalis* species on different soil types on heuweltjies or off-heuweltjies?

3.1. Monitoring of rehabilitation

Tripteris sinuata seedlings germinated and survived in all plots and persisted over the past three years with a low percentage of decline in the number of seedlings that survived from July 2001 to September 2003. *Tripteris sinuata* seedlings showed the highest survival rates in off-heuweltjie sites. This species is highly palatable (Milton 1992), it is one of the few species

whose seeds are available to farmers in the winter rainfall Karoo and can help increase the productivity of the veld. It can, therefore, be recommended for use in the rehabilitation of old fields in the Succulent Karoo.

Evaluating mechanical cultivation methods proposed to increase water infiltration and improve root development, showed different results. The number of seedlings that germinated and survived varied significantly between cultivation methods. *E. calycina* and *C. dregeanus* mostly performed well on Ploughed treatments with deeper furrows. *Tripteris sinuata* had the highest survival rate on Tilled treatments. Overall, the Tilled cultivation method yielded the highest number of seedlings in 2001 and the greatest number of persisting seedlings until 2003.

Planning of mechanical cultivation is essential to avoid soil erosion. Soil erosion is a serious problem in arid and semi-arid environments. In the rehabilitation trial on the Worcester Veld Reserve the Ploughed and Disked treatment was done along the slope, which caused very serious soil erosion (Plate 3) in all the blocks. This could have influenced the result of the rehabilitation trial. Generally ploughing on sloped areas should be done using the convention of following the contours of the landscape in order minimize soil erosion. Cleared and control treatments used as cultivation method do not have any physical soil disturbance.



Plate 3. Disking along the slope resulted in soil erosion and loss of topsoil.

Mechanical cultivation enables better water infiltration, enhancing the germination of seeds and establishment of seedlings (Griffith *et al.*, 1984). Soils that have been subsoiled in trials show that there are three beneficial changes in soil properties caused by deep loosening. These changes are increased infiltration rate, increased water availability and better root growth (Davies *et al.* 1982). From the result showed the Tilled mechanical cultivation is most promising practices to use for the restoring old fields.

In the first year of reseeding in 2000 only four species germinated. The seed selection was based mainly on the adaptability to grow in open spaces. In addition, seed selection strategies for rehabilitation programs need to consider plant and micro-organism interactions. There are advantages to selecting plants that form good symbiotic relationships with soil microbes, including mycorrhiza and cryptobiota, as these increase the nutrient uptake abilities of the plant and improve drought tolerance (Dean and Milton 1994).

3.2. Invasion of *O. pes-caprae*

O. pes-caprae is a noxious weed in many countries and can spread easily in disturbed areas. It can form dense mats on the ground, thereby out-competing native plant species for light and inhibiting their germination (Brooks 2001). Why should we be concerned about the spread of *O. pes-caprae* on heuweltjies? Heuweltjies are one of the characteristic features of the Succulent Karoo landscape, and differ from the surrounding areas both in vegetation and soil composition. The nutritional value of palatable plants that grow on heuweltjies is higher than for plants on off-heuweltjie sites due to the high soil nutrient content (Milton and Dean 1990). Invasion of these unique areas (heuweltjies) by *O. pes-caprae* decreases biodiversity and productivity of this valuable resource. Additionally, the leaves contain oxalic acid, which gives them a sharp sour taste. When animals eat only small quantities of these leaves it does not do much harm. But when the leaves are eaten in large quantities it is damaging, since oxalic acid can bind the body's supply of calcium, leading to nutritional deficiencies (Brooks 2001).

In its natural habitat *O. pes-caprae* does not become a dominant plant but mostly spreads by sending out underground stems at an angle, thereby allowing the contractile root to pull the new bulbils sideways (Putz 1994). In disturbed habitats *O. pes-caprae* is predominantly spread through dispersal of their numerous bulbils. The number of bulbils increases with an increase in the magnitude of disturbance and each plant can potentially produce 20-40 bulbils (Figure 14) (Galil 1968). The second factor that increases the spread of *O. pes-caprae* is soil disturbance by small mammals (Galil 1967). During the process of rehabilitation, disturbance of the soil by tilling, ploughing or disking has the same effect, resulting in the spread of this species and potentially threatening the success of any rehabilitation trial. No other *Oxalis* species were recorded on the rehabilitation trial.

3.3. Attempts to control *O. pes-caprae*

Generally it is impossible to recreate ecosystems that are completely free of weeds, but it is important to remove weeds that threaten biodiversity, influence succession and decrease productivity of old fields. It is important to control the weeds in a rehabilitation site, because weeds compete for water, nutrients and space. Germination and establishment of seedlings are the most determinant factors in the successes of rehabilitation attempts.

There are different methods to control weeds, some of these including hand pulling, spraying with chemicals and solarisation using black plastic on a hot day (Brooks, K. 2001). Weed control methods differ according to the type or situations of weeds, each with its own advantages and disadvantages. The time of chemical application is an important stage in controlling *O. pes-caprae*. In Australia spot spraying on infested areas was found to be the most effective just prior to flowering at the time of maximum old bulb exhaustion and minimum new bulb development. At this stage bulbs are depleted of nutrients, plants are committed to flowering and the majority of leaves have emerged (<http://incweeds.ucdavis.edu/alert/alrtoxal.html>). This method could be used to control *O. pes-caprae* on heuweltjie sites.

Oxalis species are easily stressed by dry a spell, which reduces the effectiveness of systemic herbicides. Therefore the application needs to coincide with the relative moist growing periods. Metsulfuron methyl is used in Australia to control *O. pes-caprae* along roadsides and in bushland. It has the active ingredient 600g/kg metsulfuron methyl, and should be diluted to 1 g in 100L for spot spraying on the field (Brooks 2001). Care must be taken to avoid off-target damage when using herbicides.

In 1961 and 1962 two Australians Dr R.D. Hughes and Prof. H.F. Lower respectively attempted to find a biological control for *O. pes-caprae*, but such a control was only found

much later by Kluge and Claassens (1990). They proposed the *Klugeana philoxalis* moth larva as a biological control agent for *O. pes-caprae*. Larval feeding can devastate the aerial growth of the plants. *O. pes-caprae* is most vulnerable when the parent bulbs become exhausted, but before new bulbils are fully formed (Kluge and Claassens 1990). This biological control species shows sufficient host specificity and potential for damage to be considered as a candidate for the biocontrol of *O. pes-caprae* (Kluge and Claassens 1990). Using this biological control mechanism will be environmentally sound and it is a cost-effective method of control.

3.7. Rehabilitation cost

Reseeding with indigenous species could increase plant densities and biodiversity on old fields. There is no quick way to restore mismanaged or degraded land and also there is no cheap way of restoring damaged land on arid and semi-arid areas. Degradation beyond certain critical stages may be so severe that areas may never recover (Esler and Kellner 2001). According to Snyman (1999) rehabilitation of semi-arid environments is mostly expensive and time-consuming, and necessitates thorough planning. Generally, farmers are interested only in less expensive methods, because rehabilitation contains an element of risk. The interval between actual rehabilitation and the reaping of benefits of such rehabilitation attempts in semi-arid areas may be longer than the life span of one person.

In 2001, the average market value of grazing land in this region was ± R300/hectare (Botha pers.comm.). The cost of land preparation was estimated to be R130/hectare (Disked), R185/hectare (Ploughed), R103/hectare (Tilled), R103/hectare and R40/hectare (Cleared) (Muller and Archer 2001). Tilling has the lowest cost in terms of land preparation and this cultivation method also results in the highest germination and survival of seedlings. This method can therefore be recommended for use in the rehabilitation of old-fields.

Due to both the cost of rehabilitation and the current land price, landowners are often not motivated to invest in the potential long-term benefits of increased biodiversity and productivity. Therefore governmental regulations and policies are needed to create incentives for farmers to restore, and these rehabilitation attempts should not be left as being the responsibility of future generations.

3.5. General principles for ecological rehabilitation on old-fields.

- Use indigenous plant species that are locally adapted to the site
- Select seeds mixtures of different species that allows for quick erosion control and long-term soil structure enhancement (Pyke and Archer 1991).
- Include species that have the ability of nitrogen fixation to enhance soil fertility (Woldemeskel and Sinclair 1998). There are advantages to selecting plants that form good symbiotic relationships with soil microbes, including mycorrhiza and cryptobiota, which increase the nutrient uptake abilities of the plant and drought tolerance (Dean and Milton 1994, Allsopp and Stock 1993). As a result, mycorrhizal plants are often more competitive and better able to tolerate environmental stresses than are non-mycorrhizal plants (Gianinazzi-Pearson, 1996).
- Set clear ecologically and economically feasible goals for rehabilitation.
- Use appropriate methods of land preparation, which retain and capture maximum resources (organic matter, nutrients and water) (Ordie and Baumhardt 2003).

3.6. Further research

Methods that increase soil organic matter; water holding capacity and nutrients dynamics in a non-agricultural system is still rather understudied (Dean and Milton 1994). Therefore it is important to carry out studies that assess how to increase the soil moisture level in arid and

semi-arid old fields in order to increase the rate of seedling germination and seedling establishment.

- It is important to identify and study indigenous plant species that are locally adapted to the site and serve as sheltering “nurse plants”. This can minimize the failure of seedlings. Many Succulent Karoo plant species are dependant on nursing plants for survival of seedlings. Therefore identification of such species could help farm managers to minimize their costs by reducing repetitive reseeding of the field.
- The main factors that affect the success of rehabilitation in arid environments are limited water availability, loss of biodiversity, loss of topsoil and temperature extremes (Call and Roundy 1991). Precipitation in arid and semi-arid ecosystems is more variable than in other ecosystems, thus plant establishment often occurs when precipitation is high. In many arid and semi-arid areas the agricultural practise of tied ridge cultivation systems increases soil moisture. These methods increase soil moisture by controlling water runoff from the ridges or furrows. Therefore it merits further studies that combine these practises with ploughed and disked cultivation treatments. Furrow disking is a soil and water conservation practice that is versatile and can be adapted to drylands (Plate 4). Therefore this integrated method of cultivation could be beneficial to introduce into the Succulent Karoo which has low and unpredictable rainfall. As shown in the picture the water will accumulated in furrow which could lead to a better water percolation into the soil and prevent runoff. This could help the seedling to have soil moisture for long period.



Plate 4. Runoff of rain is retained by furrow dikes for continued infiltration (right) but this water is lost from undiked (left) fields. Source (Ordie and Baumhardt 2003).

Potential studies on *O. pes-caprae* that may help to understand the effect of this species in the rehabilitation of old-fields include:

- Study of the dispersal mechanism of *O. pes-caprae* in disturbed areas can help to develop means of control on heuweltjies sites.
- Studies into the phenotypic variation of *O. pes-caprae* can help to understand the evolutionary unstable tristylous breeding system of this species. *O. pes-caprae* shows different extents of invasiveness in different parts of the world. These differences in the extent to which it becomes invasive may be related to the phenotypical variation displayed by *O. pes-caprae*. It is therefore important to study the phenotypic variations displayed by this species in its native environment here in South Africa.
- Studies into the morph frequency ratios in populations of *O. pes-caprae* in natural and disturbed areas to understand which morph is more invasive in southern Africa. In other parts of the world the short morph is the aggressive invader.
- An assessment of effective chemical control of *O. pes-caprae* in southern Africa, since biological control has thus far not been successful.

3.7. References

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