THE EVALUATION OF VARIOUS RESEEDING METHODS FOR RESTORING OLD CROPLANDS IN THE HIGHVELD REGION OF SOUTH AFRICA

by

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Summary

In spite of the relative simple vegetation structure, the Grassland biome has surprisingly high species diversity. The Grassland biome is also the most transformed biome in South Africa, with cultivation having the largest impact. When croplands are abandoned, secondary succession leads to low diversity *Hyparrhenia hirta* dominated grassland. A combination of two seed mixtures, two seeding densities and two establishment methods was established in plots on a recently abandoned cropland at Suikerbosrand Nature Reserve to evaluate their effect on secondary succession. The rip plots, where more resources were available between the rip lines, have shown higher densities of relic weeds as well as local perennials, showing some progressive successional movement. However, *Hyparrhenia hirta* was one of the non-sown perennials increasing in the rip plots. *Hyparrhenia* invasion and relic weeds were best controlled in the plough plots. Although *Hyparrhenia* was successfully controlled in plough plots, no secondary succession occurred in these treatments.

Key words: Grassland Biome, Highveld region, ecological restoration, old croplands, reseeding, secondary succession, weed control.

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CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

This chapter provides a general introduction to the Grassland Biome in South Africa (focus and location of this study) and the current conservation status of this biome. It also gives an overview of literature regarding restoration ecology with some focus on cropland restoration and reseeding. The chapter ends with a focus on research with regard to this particular kind of restoration.

1.1. The Grassland Biome

Since the term “Biome” was coined and applied by Clements & Shelford (1939) it became increasingly popular in the scientific world. A biome can be defined as a simplified, high-level unit having a similar vegetation structure and microclimatic conditions and hosting a broadly similar biotic community (Mucina & Rutherford 2006). Cox and Moore (2000) describe a biome as a “large-scale ecosystem”.

The most cited works on biome classification in southern Africa are those of Rutherford & Westfall (1986, 1994) and Low & Rebelo (1996) followed by the seminal work of Huntley (1984). The most recent vegetation classification, which includes biomes, bioregions and vegetation units, was carried out by Mucina & Rutherford (eds.) (2006). In this authentic vegetation classification, nine biomes are recognized in southern Africa, namely Fynbos, Succulent Karoo, Desert, Nama-karoo, Grassland, Savanna, Albany Thicket, Indian Ocean Coastal Belt and Forest (Figure 1.1). The Grassland Biome is the second largest biome, after the savanna biome, comprising 27.9% of southern Africa’s surface area.

According to Mucina and Rutherford (2006) the term “grassland” refers to herbaceous vegetation with a relatively short and simple structure that is dominated by graminoids, usually of the family *Poaceae*. Woody plants are rare (usually medium sized shrubs) or absent or are confined to specific habitats, such as small escarpments and rocky outcrops (“koppies”). The soils are usually deep and fertile and precipitation strongly seasonal. However, due to high precipitation and constant soil leaching, most soils in the Grassland Biome are somewhat acidic.

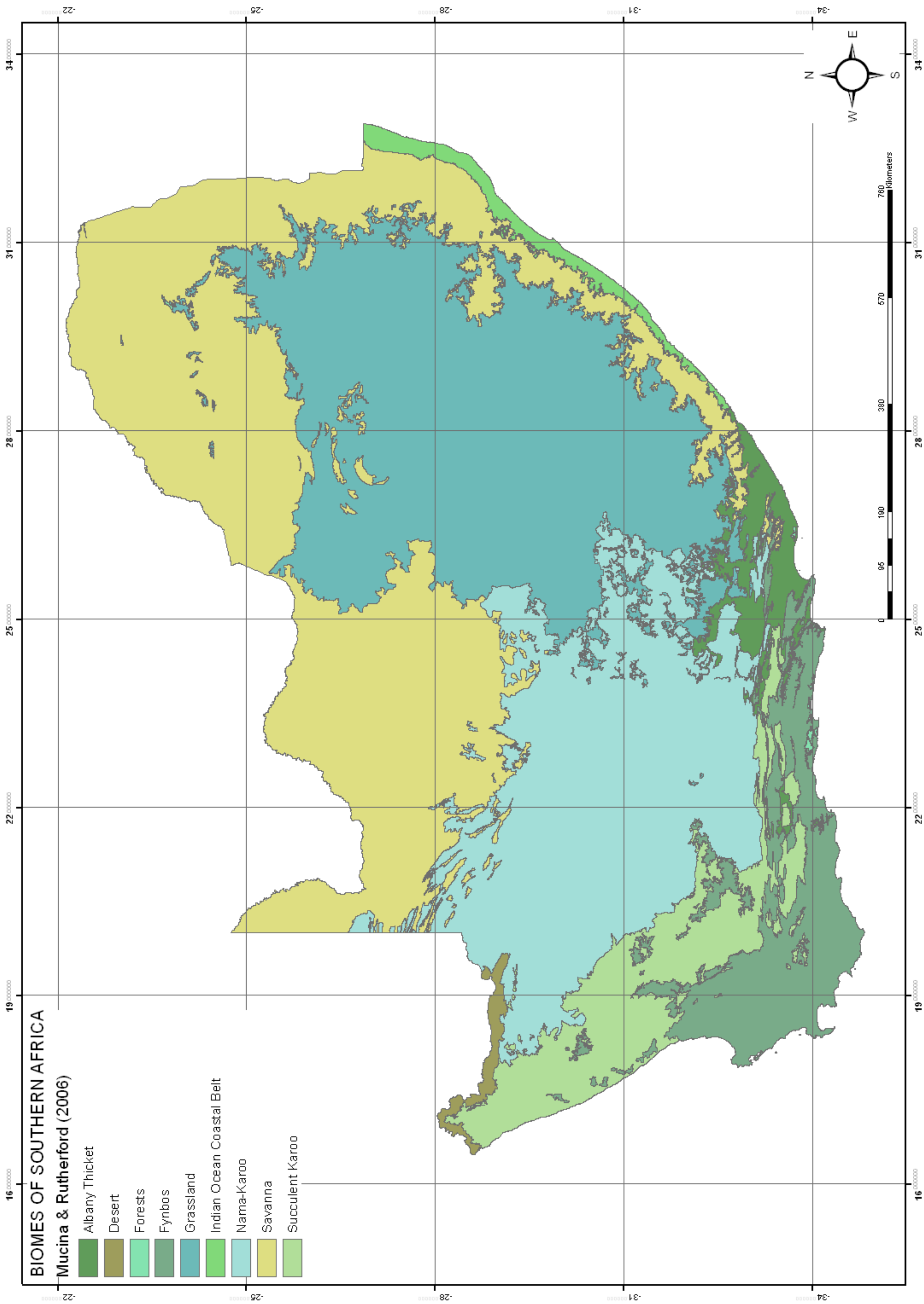


Figure 1.1: The Biomes of southern Africa according to Mucina & Rutherford (2006)

Two temperate grassland types are recognized in South Africa. Firstly, the high altitude, endemic rich, C_3-dominated, cool temperate grasslands of the Drakensberg, which has mountain summit connections up to East Africa as well as Fynbos lineages, such as *Ehrharta* spp. (Verdoorn *et al.* 2003). The second temperate grassland type in South Africa is the C_4-dominated Highveld grassland, which occurs both under dry and mesic conditions. In the Highveld grassland, in which this study was conducted, endemics are rare, as appose to the Drakensberg grasslands. If endemics are present, they are mainly found in quartzite sourveld communities.

The South African Grassland Biome (latitude 25º to 33º S) is part of the global Temperate Grassland Biome, which comprises the Eurasian steppes and American grasslands in the northern hemisphere as well as the Argentinean pampas, the Australian Alps grasslands and the Tussock grasslands of New Zealand in the southern hemisphere. The Grassland Biome elsewhere in Africa is relatively poorly represented and is generally confined to mountain summit patches. South Africa's Grassland Biome occurs mainly on the high central plateau (Highveld), the inland areas of the eastern seaboard, the mountainous areas of KwaZulu-Natal and the central parts of the Eastern Cape. The topography is mainly flat to rolling, but also includes mountainous regions and escarpment (Mucina & Rutherford 2006).

The temperate grasslands of South Africa occur where there is a strong summer rainfall with winter drought. The rainfall may vary from 400 mm – 2 500 mm per annum, which relates strongly with other parts of the world with similar vegetation (Mucina & Rutherford 2006). Frost, which generally increases on the gradients of altitude and latitude, is a common phenomenon in the Grassland Biome. The coldest periods, normally between June and August, are often exacerbated by aridity. These grasslands also have high lightning flash occurrences, causing lightning-induced fires to be a relatively high possibility (Schulze 1984). The grasslands are therefore historically a fire prone ecosystem, making fire a vital element in the maintenance of both its structural and textural patterns (Everson 1985, Bainbridge 1993, O'Connor & Bredenkamp 1997). Grazing also has a major influence on vegetation structure as well as the species composition (Owen-Smith & Danckwertz 1997).

1.1.1. Origin of the South African Grassland Biome

The origin of the South African grasslands, particularly regarding the lack of trees, has been much speculated in the past, including some serious scientific analysis. Acocks (1953) ascribed the vast open grasslands to human (agriculture) activity, which destroyed large areas of forest. Tinley (1982) suggested that woody elements are excluded due to the waterlogging desiccation effect of shallow pan horizons in the soil. Ellery *et al.* (1991) suggested that climate contributes by maintaining a disturbance (fire and grazing) regime that excludes woody plants. Rutherford & Westfall (1986) also mentioned that the major environmental factor, separating at least some grasslands from savanna, is summer aridity in combination with winter minimum temperatures. This, again, leads to "phanerophyte exclusion", resulting in the absence of a major woody component. Bredenkamp *et al.* (2002) also suggest that southern African grasslands were not only determined by conditions of drought, but also by cooler conditions at high altitudes which are one of the major driving forces that prevent colonisation by trees of a generally tropical origin. The first two theories have been largely rejected (Meadows & Linder 1993, O'Connor & Bredenkamp 1997).

1.1.2. Vegetation structure

Grasslands have a relatively plain vegetation structure and are strongly dominated by the grass family, *Poaceae*. The canopy cover is highly moisture dependent and will decrease as moisture availability decreases. Minimum temperatures play a decisive role in structurally distinguishing temperate grasslands from forests and savanna where frost is rare (Walker 1993). Forbs are a very important part of grasslands, and although they are mainly sub-dominant, they contribute much to local diversity. Annual plants usually only occur in disturbed areas and are less common than in arid savanna regions.

The main aboveground driving force influencing vegetation structure within grasslands in South Africa is competition for canopy space amongst individual plants. Competition for canopy space, again, is strongly influenced by herbivory (grazing pressure), rainfall (plant available moisture), soil type (nutrient availability) and fire, which are all strongly interactive (Diaz *et al.* 1992, Walker 1993). The functional genetic make-up of species obviously plays an important part in adaptability and subsequent vegetation structure of grasslands. These factors are important in this study where restoration strives to obtain similarity to the original natural vegetation structure and texture.

The most common grass subfamily in the Grassland Biome of South Africa is that of *Panicoideae*. This is a major C_4 photosynthesis pathway (photosynthesise in warm climates) group that tends to dominate the grass component of grassland and savanna ecosystems. Temperate grasslands, on the other hand, tend to be dominated by C_3 photosynthesis pathway (photosynthesise in a cold climate) grasses (Gibbs Russell *et al.* 1991).

1.1.3. Species richness

Data on plant species richness in all regions of the Grassland Biome of South Africa are generally sparse (Cowling *et al.* 1989). In high altitude grassland of the Eastern Cape and KwaZulu-Natal, a 100 m^2 plot may contain 9 – 39 species within vegetation having a single uniform grass layer (Eckhardt *et al.* 1996). In specialised habitats, with multi-structural habitats, such as rocky outcrops, the number of species might increase by ten or more (Hoare 1997). According to Hoare (2003), there is a curvilinear relationship between species richness and the amount of surface rock in temperate grasslands. In general, a 1 000 m^2 plot in grassland may contain anything from 55 – 100 species with a mean of 82 species/1 000 m^2 (Table 1.1). In the Highveld grassland alone there are almost 4 000 species and this region contains centres of diversity for many *speciose genera* (Cowling *et al.* 1989).

Table 1.1: Mean species richness per 1 000 m^2 of some of the biomes in South Africa (van Wyk 1998).

Biome/Veld type	Number of Species
Renosterveld	86
Grassland	82
Succulent karoo	74
Fynbos	68
Forest	51
Nama karoo	47

Management of grasslands can have a strong influence on species richness and species composition by affecting competition interactions among species. For example, communal land with traditionally high livestock stocking rates in the Eastern Cape has 24 species per 100 m^2 in comparison with 34 species in commercial managed land with the same environmental attributes. Poorly managed grasslands also tend to have more exotic plant species and less grasses in the composition (Hoare 2002).

1.1.4. Conservation status

Land cover data indicate that nearly 30% of the Grassland Biome in South Africa has been permanently transformed (Table 1.2), mainly as a result of cultivation (23%), plantation forestry (4%), urbanisation (2%) and mining (1%). A significant part of the remaining portion may be secondary cultivated lands or degrading due to current or previous gradual woody encroachment (Fairbanks *et al.* 2000), which brings the total destroyed grassland to about 60%. Ground surveys of land cover in the Eastern Cape, with dense rural populations, indicate that up to 80% of "natural grassland" might in fact be old lands with secondary vegetation (Hoare 1997). The conversion of natural ecosystems for intensive agricultural or forestry production, or for grazing purposes, has been identified as major pressures on plant diversity (Cowling & Hilton-Taylor 1994). The eventual successful rehabilitation of such converted areas is an increasingly important conservation opportunity, which perhaps already became a necessity rather than an option.

Red Data Species

The Grassland Biome contains 640 Red List species (Hilton-Taylor 1996). This number excludes species, which are categorised as "not threatened". Of this list 136 species are threatened with extinction and six are already extinct. There are only nine grasses on this list.

Table 1.2: Habitat transformation and protected status of biomes in South Africa, Lesotho and Swaziland. Only statutory reserves and parks were considered (Mucina & Rutherford 2000).

Biomes	Area (km²)	% Transformed	% Remaining	% Protected
Albany Thicket	29 127.547	2.30	88.02	6.06
Desert	7 166.443	0.57	99.16	14.56
Forest	4 731.407	0.37	94.08	16.73
Fynbos	83 946.257	6.62	68.79	10.10
Grassland	354 593.501	27.97	64.96	1.68
Indian Ocean Coastal Belt	14 282.489	1.13	50.71	1.54
Nama-Karoo	248 278.626	19.59	97.65	0.61
Savanna	412 544.091	32.54	77.06	8.75
Succulent Karoo	83 283.976	6.57	94.64	2.93

1.1.5. Transformation of grasslands

The conversion of natural grasslands to row-crop agriculture alters the structure, function and complexity of grassland soils (Rover & Kaiser 1997, Elliot 1986, Anderson & Coleman 1985). Although plant communities recover from disturbance through natural succession, many aspects of community structure are slow to return without human intervention (Pywell *et al.* 2002). This is particularly the case in old cultivated lands, where physical and chemical soil properties have been severely transformed and the natural seed bank entirely removed. Such ecosystems apparently cannot recover without interventions designed to correct the specific changes that led to the so-called “threshold of irreversibility” being crossed. For example, reconstitution of seed banks might be needed, or the restocking of soil organic matter and micro-organisms that promote higher plant establishment and growth (Aronson *et al.* 1993).

However, Ehrenfeld (2000) stated that in many instances disturbed grasslands can be re-vegetated, but can never be completely restored. Although the restoration of degraded grasslands are both appropriate and necessary, they should be recognized for what they are, without the pretence that they result in a replica of the original, "natural" system. Restoration thus has limitations and these should be realistically recognized (Ehrenfeld 2000).

1.2. Ecological Restoration

1.2.1. What is Ecological Restoration?

Generally, ecological restoration attempts to return disturbed ecosystems to its historic trajectory. The Society for Ecological Restoration (SER) defines ecological restoration, in their "SER International Primer on Ecological Restoration (2004)" simply as:

"the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed".

Other definitions for ecological restoration are:

"the intentional alteration of a site to establish a defined indigenous, historic ecosystem" (Aronson et al. 1993).

or

"The recovery of grasslands to their former state, or to a self-sustaining ecosystem" (Kellner et al. 1999).

The general goal of ecological restoration is to emulate the structure, function, diversity and dynamics of a specified "reference ecosystem". The "reference ecosystem" is a chosen ecosystem or sites used for planning and evaluating a restoration project. Implicit in this definition is the notion that restoration seeks to reassemble, insofar as possible, some predefined species inventory. However, since it is rarely possible to determine exactly what historic or prehistoric ecosystems looked like, or how they functioned, let alone establish the full species list of indigenous communities, restoration efforts may be plagued by ambiguities in both their goals and criteria of success (Cairns 1989, 1991, Simberloff 1990, Aronson *et al.* 1993).

Aronson *et al.* (1993) suggest using the terms "restoration *sensu stricto"* and "restoration *sensu lato"* to describe restoration projects. In this particular restoration study the term “restoration *sensu lato”*, which seeks simply to redirect the disturbed ecosystem in a trajectory resembling that presumed to have prevailed prior to the onset of disturbance, is used, as opposed to “restoration *sensu stricto”*, which invariably seeks a direct and full return to the indigenous, historic ecosystem. The former term is preferred due to the scale of degradation at the study site, referring mainly to the alteration of physical and chemical soil characteristics, which most likely pushed the ecosystem across the threshold of irreversibility into a completely different domain.

An inevitable question during ecological restoration projects is “when is recovery reached or restoration accomplished?” According to the SER Primer (2004) an ecosystem has recovered - and is restored – when (1) It contains enough biotic and abiotic resources to carry on its development without further support or subsidy; (2) It will sustain itself structurally and functionally; (3) It will demonstrate resilience to normal ranges of environmental stress and disturbance; and (4) It will interact with contiguous ecosystems in terms of biotic and abiotic flows and cultural interactions.

To substantiate the above guidelines, the SER Primer (2004) includes nine attributes determining when restoration has been accomplished (see below). The full expression of all of these attributes is not essential to demonstrate restoration. Instead, it is only necessary for these attributes to demonstrate an appropriate trajectory of ecosystem development towards the intended goals or reference. According to these attributes restoration was accomplished when:

- The restored ecosystem contains a characteristic composition of the species that occur in the reference ecosystem and the restored ecosystem provides an acceptable community structure.
- The restored ecosystem is dominated by indigenous species.
- All ecological functions necessary for the future development and/or stability of the restored ecosystem are represented or have the potential to develop.
- The physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory.

- The restored ecosystem apparently functions normally for its ecological stage of development, and signs of dysfunction are absent.
- The restored ecosystem is suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges.
- Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.
- The restored ecosystem is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem.
- The restored ecosystem is self-sustaining to the same degree as its reference ecosystem, and has the potential to persist indefinitely under existing environmental conditions.

From the above guidelines it is clear that some core attributes are fundamental objectives to reach during an ecological restoration project and should, if possible, be measured in order to evaluate the progress or success of such a project. Some of the more important of these core attributes are species composition, community structure, ecological processes, ecosystem functions and resilience and is defined below:

The species composition is the taxonomic collection of species present. The importance of a sufficient recovery in species composition cannot be overstated in restoration. All functional species-groups must be represented if a restored ecosystem is to preserve itself (SER Primer 2004).

By community structure is meant the physiognomy or architecture of the vegetation community with respect to the density, horizontal stratification, and frequency distribution of species-populations, as well as the sizes and life forms of the organisms that comprise those communities (SER Primer 2004).

Ecological processes or ecosystem functions are the dynamic features of ecosystems and include interactions among organisms and interactions between organisms and their environment. Ecological processes are the foundation for self-maintenance in an ecosystem. Examples of ecological processes are carbon fixation by photosynthesis, trophic interactions, decomposition, and mineral nutrient cycling.

Ecosystem functions and processes, along with the reproduction and growth of organisms, are the factors causing an ecosystem to be self-renewing or autogenic. A common goal, therefore, for the restoration of natural ecosystems is to recover autogenic processes to the point where assistance from restorationists is no longer needed. Some dynamic processes however, such as fires, floods, damaging wind, freezes and droughts, are external, and well-restored ecosystems should have the resilience to recover from such stresses (SER Primer 2004).

Resilience is the ability of an ecosystem to regain structural and functional attributes that have suffered harm from stress or disturbance (SER Primer 2004).

1.2.2. Restoration vs. Rehabilitation and other activities

Ecological restoration is one of several activities that endeavour to alter the biota and physical conditions at a site; activities that are commonly confused with the term ecosystem "restoration". The most common of these activities are rehabilitation, reclamation and ecological engineering (SER primer 2004).

Rehabilitation shares with restoration a fundamental focus on historical or pre-existing ecosystems as models or references, but the two activities differ in their goals and strategies. Rehabilitation highlights the reparation of ecosystem processes, productivity and services, whereas the goals of restoration also include the re-establishment of the pre-existing species composition and community structure.

The term reclamation, as commonly used in the context of mined land, has an even broader function than rehabilitation. The main objectives of reclamation include the stabilization of the terrain, assurance of public safety, aesthetic improvement, and usually a return of the land to what, within the regional context, is considered to be a useful purpose. Re-vegetation, which is usually part of land reclamation, may involve the establishment of only one or a few species. Reclamation projects that are more ecologically based can qualify as rehabilitation or even restoration.

Ecological engineering implies manipulation of natural materials, living organisms and the physical/chemical environment to achieve specific human goals and solve technical problems. It thus differs from civil engineering, which relies on human-made materials such as steel and concrete. Predictability is a primary consideration in all-engineering design, whereas restoration recognizes and accepts unpredictable development and addresses goals that reach beyond strict pragmatism. It also encompasses biodiversity and ecosystem integrity and health. When predictability is not at issue, the scope of many ecological engineering projects could be expanded until they qualify as restoration (SER primer 2004).

1.2.3. Restoration and Reseeding

Restoration of previously cultivated lands is almost synonymous with reseeding. The sheer numbers of weedy annual seed limits the possibility of local perennials to spontaneously re-seed long-term cultivated soils. Bartolome (1979) found an average of 6.5 germinable annual grass and forb seeds per cm^2 in a recently abandoned crop field at the Hopland Field Station, California, USA. Major and Pyott (1966) again found no seed reserve of the local perennials in a relict bunchgrass site in the Sacramento Valley. It is therefore imperative to re-seed abandoned croplands in order to re-establish a natural seed bank.

Reseeding rangelands has been shown to be both successful and economically feasible by many (e.g. Godfrey 1979, Kearl & Cordingly 1975). Successful reseeding, however, has been shown to be dependent upon aspects such as prevailing weather conditions; weed control; seedbed preparation; and sometimes, pre-treatment of seeds to enhance germination (Hessing & Johnson 1992).

The Rural Development Service of the U.K Department of Environment, Food and Rural Affairs published in their Technical Advice Note 24, (Peel 2004) called “Arable reversion to species rich grassland: establishment of a sown sward”, the following key points to consider before commencing with reseeding for arable land restoration:

- The weed burden must be reduced to a manageable level prior to sowing. This may mean delaying sowing for a year. This can be done by using mechanical or chemical methods.
- A fine seedbed should be created by using conventional tillage equipment.
- The best time for sowing is usually during early growing season.
- Ensure that an appropriate seed mix is sown, from the right source.
- Seed should be broadcasted on the soil surface and the site then rolled.
- Monitor the new grassland for evidence of pest damage, and take early action to deal with any pests.

Grassland plants, over the millennia, have developed adaptations to particular conditions whilst ecotypes of the same species have adapted to differing local conditions. For this reason a plant species inventory of the local ecosystem of reference is extremely important. It is recommended that seed that originates no more than 100 kilometres from the project site should be used. However, the availability of local grass and forb seed for restoration projects can be a major limiting factor for most restoration activities (Kilde & Fuge 2000).

A seed mixture with less than 40 percent forbs will, in a short time, result in grassland dominated by grasses. It is also recommended that forbs don't make up more than 70 percent in any mixture. Grasses provide an aesthetically pleasing vertical aspect to a grassland planting as well as structural support. If burning is part of the grassland management plan, it is important to note that grasses supply the principal fuel to carry a fire. Again, the seed mixture will ultimately depend on the species composition of the reference ecosystem, unless such a reference is absent. The oldest restored grassland, originally planted 65 years ago at the University of Wisconsin in Madison, U.S.A, maintains about 200 plant species. The greater the diversity of local plant species, the greater the long-term success of a grassland restoration (Kilde & Fuge 2000).

Research indicates that native perennial grasses do not establish well on most annual grassland sites without some form of site preparation, and that follow-up treatment is often necessary to reduce competition from the more aggressive weedy annuals (Heady 1956, McClaran 1981, Fossum 1990). Good site preparation includes developing a fine and firm seedbed, which will increase the germination rate of seed and the success of grassland plantings (Kilde & Fuge 2000). Ultimately the best technique for seeding natural perennial grasses is one that ensures good, firm contact of the seed with the soil, preferably just below the soil surface. If the seed is broadcasted on the soil surface, it needs to be covered, either by raking, harrowing, or mulching. Often the most successful establishment occurs in the area compressed by the tractor tyres (Amme & Pitschel 1989).

Figure 1.2: A specialised Truax drill planter, developed to also plant chuffy grass seed.

Species rich grassland restoration by re-introducing indigenous plant species is often faster and easier on arable land than in degraded rangeland. After sowing, seedlings can easily establish on bare soil since there is no competition with mature perennial plants. The soil nutrient status is also more favourable on arable land since the organic matter content is generally low and thus the mineralisation of organic nitrogen are lower (Plantureax *et al.* 2005).

Establishing methods for indigenous plants is not unlike those for perennial cultivated pasture crops. Several distributors in the USA have developed versions of seeding machines adapted for local species seed by incorporating three separate seed bins for the three main types of seed: light fluffy seed, small hard seed, and large hard seed (Figure1.2). By using this type of range seeding equipment, all the seed can be planted simultaneously.

1.3. Grassland restoration research

Grassland restoration “may be the oldest ecological restoration of any kind” (Mlot 1990), originating in the 1930’s with Norman Fassett and Aldo Leopold’s plan to plant a large grassland at the University of Wisconsin Arboretum, USA (Cottam & Wilson 1966, Meide 1988, Sperry 1994). The importance of grassland restoration in the USA grew from the tragic “Dust Bowl” era (see Text box below) of the 1930’s and subsequent efforts to stabilize the grasslands and agricultural ecosystems (Weaver 1943, Worster 1979). Additional interest arose because of extensive transformation of the grassland cover type to agriculture (Riebsame 1990), resulting in a documented loss of 82 – 99 % of the original tallgrass prairie grasslands, and the initiation of the Conservation Reserve Program (CRP) of the USA (Samson & Knopf 1994).

Research in South Africa on restoration of formerly cultivated lands is either insufficiently executed or poorly documented and is mainly limited to some comments by Roux (1969) on the Highveld grasslands. Past and current research on restoration ecology mostly focuses on rehabilitation of mined areas, as controlled by the South African Mineral and Petroleum Resources Development Act (28 of 2002), and restoration of degraded natural rangeland as controlled by the Conservation of Agricultural Resources Act (43 of 1983) (CARA).

Although CARA (regulation 2) expect landowners to obtain a permit for cultivating new virgin land, and the National Environmental Management Act (107 of 1998) (NEMA) enforces (regulation 386 section 12) a basic Environmental Impact Assessment (EIA) to be done for “transformation and removal of indigenous vegetation”, no legislation exists that deals with restoration or rehabilitation of old croplands.

The Dust Bowl Era

Between 1930 and 1940, the south-western Great Plains region of the USA suffered a severe drought. The semi-arid grassland was extensively converted to cropland to produce dry land wheat. As the demand for wheat products grew, cattle grazing were reduced, and millions more acres were ploughed and planted.

Dry land farming on the Great Plains led to the systematic destruction of the grassland grasses. In the ranching regions, overgrazing also destroyed large areas of grassland. Gradually, the land was laid bare, and significant environmental damage began to occur. Among the natural elements, the strong winds of the region were particularly devastating.

With the onset of drought in 1930, the over farmed and overgrazed land began to blow away. Winds whipped across the plains, raising billowing clouds of dust. The sky could darken for days, and even well sealed homes could have a thick layer of dust on the furniture. Nineteen states in the heartland of the United States became a vast dust bowl. With no chance of making a living, farm families abandoned their homes and land, fleeing westward to become migrant labourers. The Dust Bowl taught farmers new farming methods and techniques. The 1930's fostered a whole new era of soil conservation. Perhaps the most valuable lesson learned form the Dust Bowl - take care of the land. Sources:
http://memory.loc.gov/learn/features/timeline/depwwii/dustbowl/dustbowl.html
http://livinghistoryfarm.org/farminginthe30s/water_02.html

A dust cloud in south-eastern Colorado, USA, during the "dust bowl" era of the 1930's.

A better understanding of restoration ecology can offer many insights into basic ecological processes, including succession, competition, and plant population dynamics, and can also provide guidance for management of grassland ecosystems

(Kindscher & Tieszen 1998). Furthermore, restoration of degraded areas presents a valuable opportunity to test ecological theory on community recovery following disturbance (Bradshaw 1987, Ewel 1987, Hobbs & Norton 1996, Palmer *et al*. 1997).

1.4. Aims of this study

Suikerbosrand Nature Reserve (SNR), in the Gauteng Province of South Africa, recently acquired a significant area of land to extend the reserve. It is estimated that 30 – 40 % of this extended portion consists of old croplands. It is envisaged that these areas would be restored to some state **resembling the vegetation that would originally** have occurred there (Hoare 2006). This particular study was conducted on one of the above-mentioned old croplands on the extended portion of the SNR.

The objective of this restoration study is to investigate various reseeding methods in order to make **recommendations for old cropland restoration** within the SNR as well as the Highveld region as a whole. More specifically the study, which consists of a combination of two seeding establishing methods, two seed mixtures and two seeding rates, aims to evaluate these combined treatments in terms of:

- effectiveness in establishing the sown species to control relic cropland weeds;
- resemblance to the natural rangeland in terms of species composition;
- occurrence of new entrant species during secondary succession; and
- cost of restoration trials.

1.5. Format of the dissertation

The dissertation consists of 5 chapters. As mentioned in the beginning, this particular chapter provides a general introduction to the Grassland Biome in South Africa and the current conservation status. It also gives a general introduction to restoration ecology and focuses on reseeding, which is vital to restoration of formally cultivated lands. Chapter 2 gives a detailed description of the study area. Chapter 3 describes the experimental design and methodology followed during data sampling and analysis. Chapter 4 gives a detailed account of the results as well as a discussion with each result. Chapter 5 gives a general conclusion as well as recommendations for cropland restoration and further research in the Highveld region of South Africa.

CHAPTER 2
STUDY AREA

2.1. Location

The study was conducted within the Suikerbosrand Nature Reserve (SNR), located in the southeastern section of the Gauteng Province of South Africa. The nearest major town, located southeast of the reserve, is Heidelberg (Figure 2.1). The reserve is situated on the inner central plateau of South Africa, the so-called “Highveld” area, and is approximately 40 km southeast of the city of Johannesburg, 80 km south of the city of Pretoria, and 28 km from the OR Tambo International Airport.

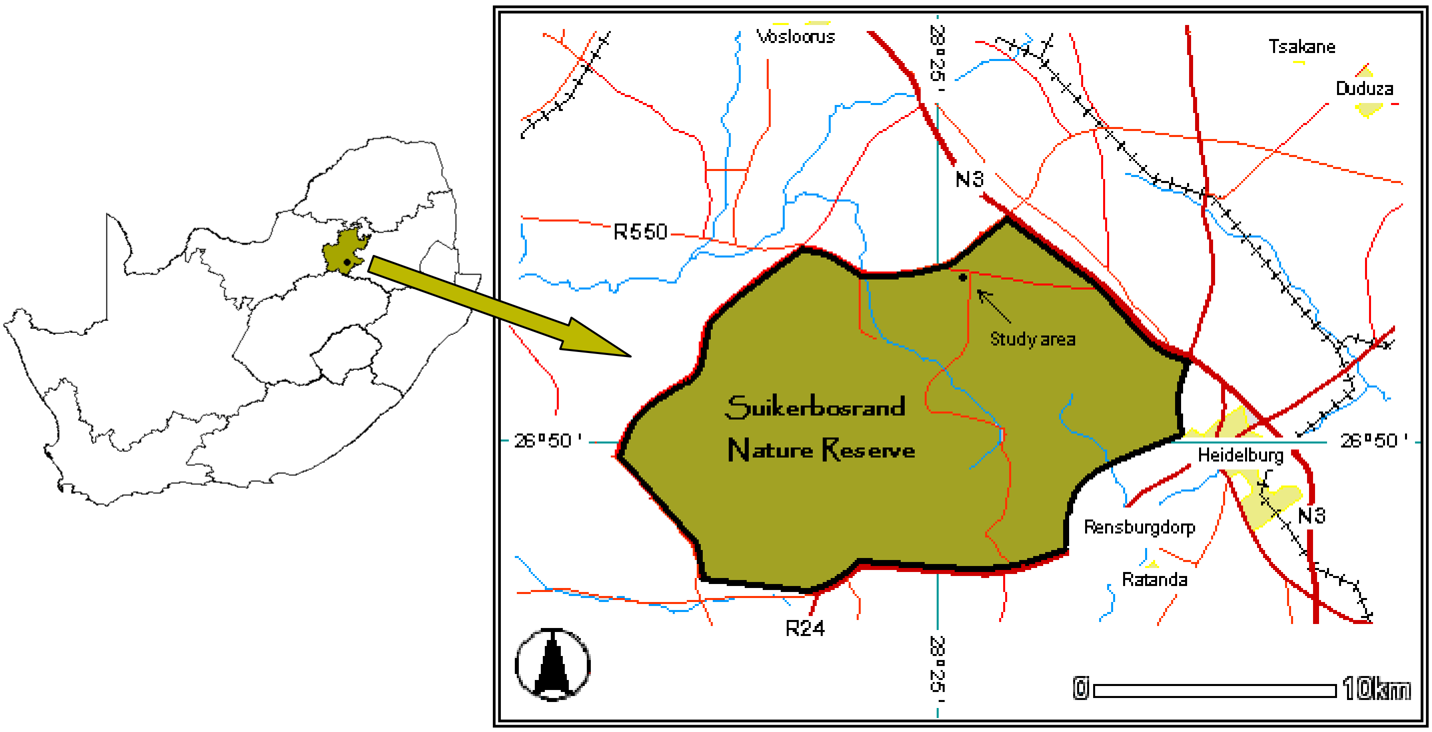


Figure 2.1: Orientation map, showing Suikerbosrand Nature Reserve in relation to major towns in the area. The black spot in the upper part of the reserve shows the location of the study area.

The study area is located in the central northern part of the reserve on a portion that was newly acquired to extend the reserve. These areas were previously largely cultivated for agricultural purposes (Figure 2.2). Unlike the older part of the reserve in the south, which mainly consists of rocky hills and mountainous terrain, with well-established natural woody pockets, this new portion comprises mostly of old lands and somewhat degraded open grassland.

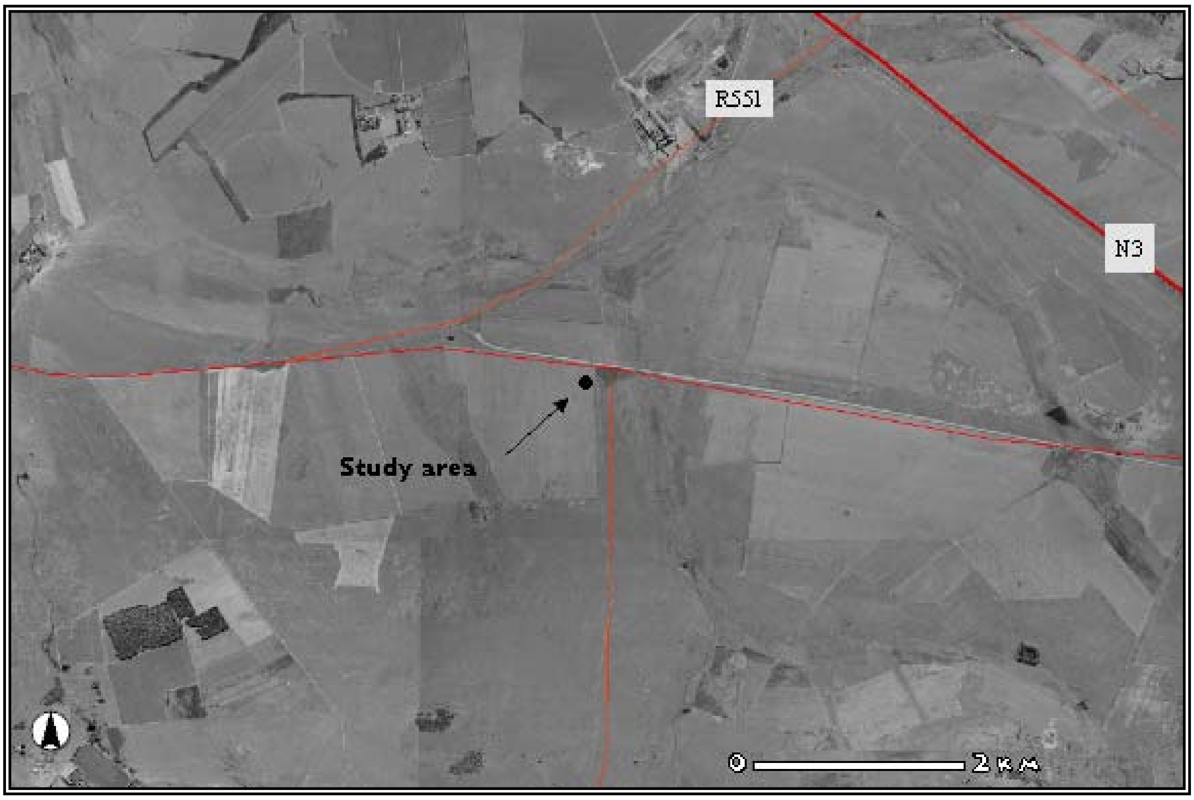


Figure 2.2: Ortho photograph, showing mainly the northern portion of Suikerbosrand Nature Reserve and the many cultivated lands within this area (AGIS 2007).

2.2. Climate

Climate, broadly spoken, is a major determinant of the geographical distribution of species and vegetation communities. Within any area of general climatic uniformity, local condition of temperature, light, humidity and moisture varies. These factors add to the local microclimate and play an important role in the production and survival of plants and plant species. In agricultural terms, within any particular region, it is the microclimate that is of most direct concern for food production. For ecological conservation, microclimate adds to valuable biological heterogeneity within a given area (Tainton & Hardy 1999).

The Köppen climatic classification is world-wide recognised as a classic broad climatic classification system. According to Köppen (1931), it is often preferred to describe the general climate of a given area because of its universality in usage and its relative simplicity in regard to input data requirements. This system is a hierarchical classification system with up to three levels of detail that is based on rainfall magnitudes, rainfall seasonality, and rainfall concentration. It also includes durations above or below threshold temperatures on a monthly basis. Input requirements are, therefore, monthly precipitation and temperature data (Schulze *et al.* 2006b). According to the Köppen classification the study area falls, as with most of the Highveld region of South Africa, within the Cwb class, of which the climatic characteristics translates to (see Table 2.1 for all Köppen climate classes in South Africa):

C – Moist with cold winters
w – Dry winters
b – Summers relatively long and cool

The Cwb class is typical of the Highveld region, which represents a significant portion (14.61%) of South Africa (Table 2.1).

Table 2.1: Percentage of Köppen climate classes in South Africa (Schulze *et al.* 2006). The bold typed row (Cwb) indicates the general climate for the study area.

Köppen	Class Climatic Characteristics	% in South Africa
Aw	Tropical wet, dry winter season	1.53
BSh	Semi-arid, hot and dry	15.55
BSk	Semi-arid, cool and dry	17.95
BWh	Arid, hot and dry	16.34
BWk	Arid, cool and dry	9.97
Cfa	Wet all seasons, summers long and hot	4.69
Cfb	Wet all seasons, summers long and cool	8.1
Csa	Summers long, dry and hot	0.24
Csb	Summers long, dry and cool	0.89
Cwa	Winters long, dry and hot	10.1
Cwb	**Winters long, dry and cool**	**14.61**
Cwc	Winters dry, summers short and cool	0.02

2.2.1. Precipitation

Under non-irrigated conditions the mean annual precipitation (MAP) gives an upper limit to a region's sustainable agricultural potential in regard to biomass production if other factors (e.g. light, temperature, topography, soils) are not limiting (Schulze *et al.* 2006a). Because annual precipitation for the whole of South Africa is relatively low (MAP = 526,7 mm/annum) (Lynch 2004) and evaporative losses high, plant moisture stress is a factor that exerts a major influence on plant production and survival. Rainfall is therefore the factor that mostly determines the composition and distribution of plant communities as well as the production potential of these communities (Tainton & Hardy 1999).

The MAP for Gauteng province is listed at 668 mm/annum by Dent *et al.* (1989) and 647 mm by Lynch (2004). At SNR the MAP is slightly higher than the values given for the larger province. Data collected from the Diepkloof weather station, located at the office complex within the SNR, indicate a mean annual rainfall of 689 mm/annum during a period of 23 years (1981 – 2004), with December being the highest rainfall month and July the lowest (Figure 2.3). The highest rainfall per season recorded during this 23 year period was 1 039 mm (1995/96) and the lowest 424 mm (2002/03), indicating significant fluctuations from season to season.

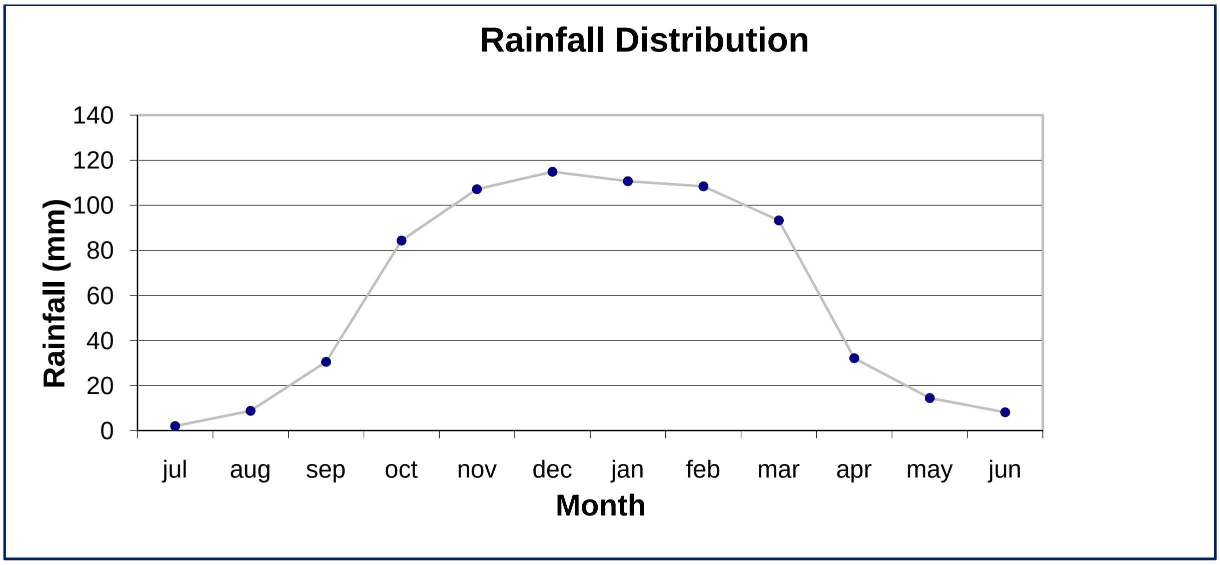


Figure 2.3: Monthly rainfall (mm) distribution at the Diepkloof weather station in SNR.

Median annual rainfall classes (33rd percentile values), compiled from the Agricultural Research Council (ARC) and South African Weather Service (SAWS) weather station data, with a recording period of 10 years or more, indicates that the new lower lying portion of the reserve, where the study area is located, receives less rain per annum (<600 mm/annum) than the elevated more hilly portion of the reserve towards the south (>600 mm/annum) (Figure 2.4).

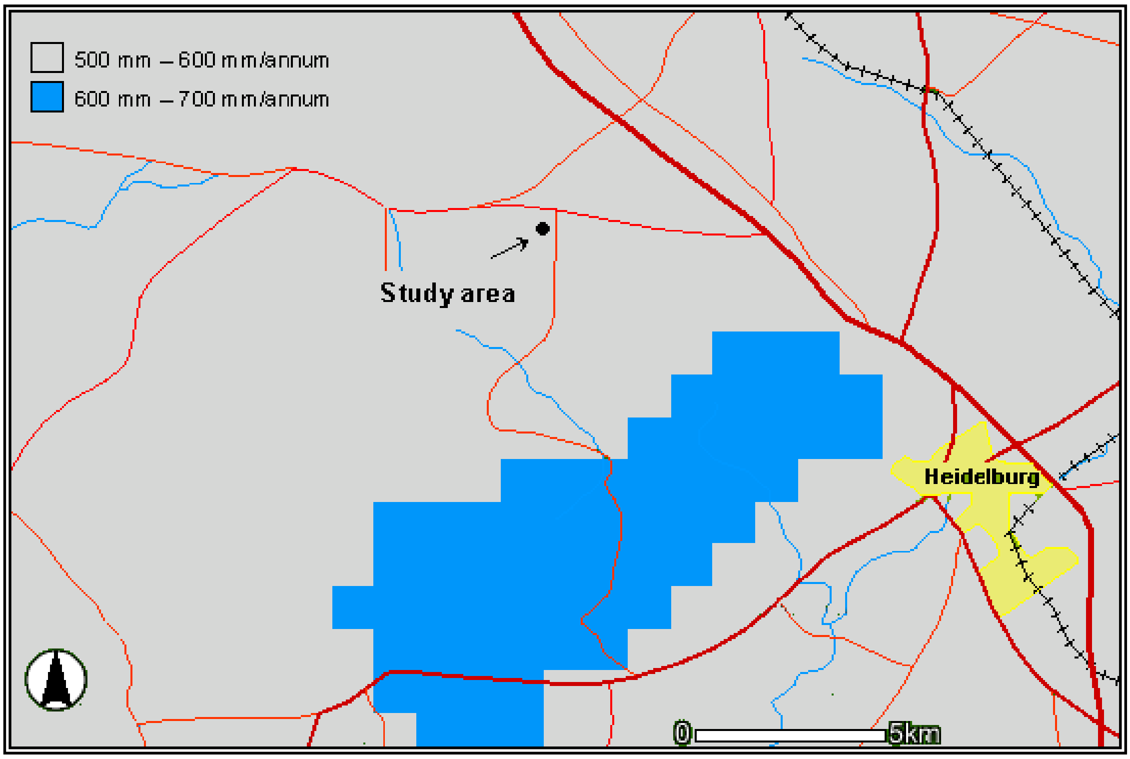


Figure 2.4: Median annual rainfall classes for SNR area. Light grey represent an annual rainfall class of 500 – 600 mm/annum (plains) and the blue area 600 – 700 mm/annum (hills) (AGIS 2007).

For ecological restoration it is important to note that the most important attribute to ecosystem function is not only the amount of rainfall, but also the efficient usage thereof. Rain usage efficiency is greatly influenced by vegetation cover and equals the slope of the relationship between annual rainfall and aboveground phytomass production (Le Houerou 1984). Therefore, un-restored, recently abandoned croplands, with its lower vegetation cover and higher rate of runoff, will be less efficient in rainfall usage.

2.2.2. Temperatures

As with most environmental factors, it is not the mean but the extremes that determine the survival rate of plants and animals (Tainton & Hardy 1999). This is particularly true for temperature in the Highveld region of South Africa, where low temperatures and severe frost restrain the growth of indigenous woody plant species. Although most of SNR offers enough natural protection against the effect of low temperatures for a wide variety of trees and shrubs, much of the reserve comprises open grassland, exposed to low temperatures. Subsequently, little to no indigenous trees occurs in this area, which can be described as "natural climatic climax grassland" (Tainton & Hardy 1999).

The mean annual temperature for SNR is 16.0°C, slightly lower that the mean annual temperature for Gauteng, which is 16.8°C (Schulze & Maharaj 2006). Data from the nearest SAWS weather station, situated at OR Tambo International Airport, which is about 28 km from the reserve, shows the hottest months to be December, January and February. All three these months have a daily mean temperature of above 25°C, while the coldest months are June and July, with daily mean temperatures of 10.1°C and 10.4°C respectively (Figure 2.5). The mean monthly maximum annual temperature is 26.6°C. The average range between maximum and

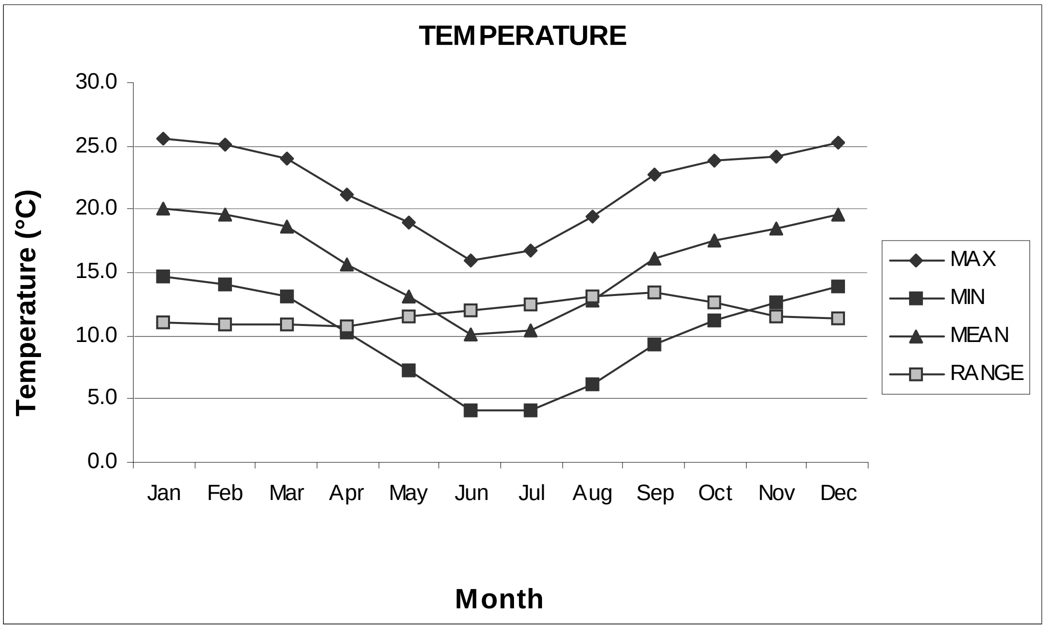


Figure 2.5: Monthly maximum, minimum, mean and range of temperatures for the OR Tambo International Airport weather station, using data covering a period of 29 years (1961 – 1990).

minimum daily mean temperatures for all the months is 11.8°C. The highest temperature recorded during the 29-year period was 35.4°C in January 1973 and the lowest -8.3°C in June 1979.

According to Figure 2.6 there is an approximate 2 ºC difference in mean minimum temperature between the open grassland area, where the study area is located (0.1ºC - 2ºC) and the more protected hilly country towards the south of the reserve (2.1ºC - 4ºC). This map was compiled from ARC and SAWS weather stations data representing a temperature-recording period of 10 years or more. Regression analysis was used to relate available temperature data averaged per ten-day period to topographic indices such as altitude, aspect, slope and distance from the sea (AGIS 2007).

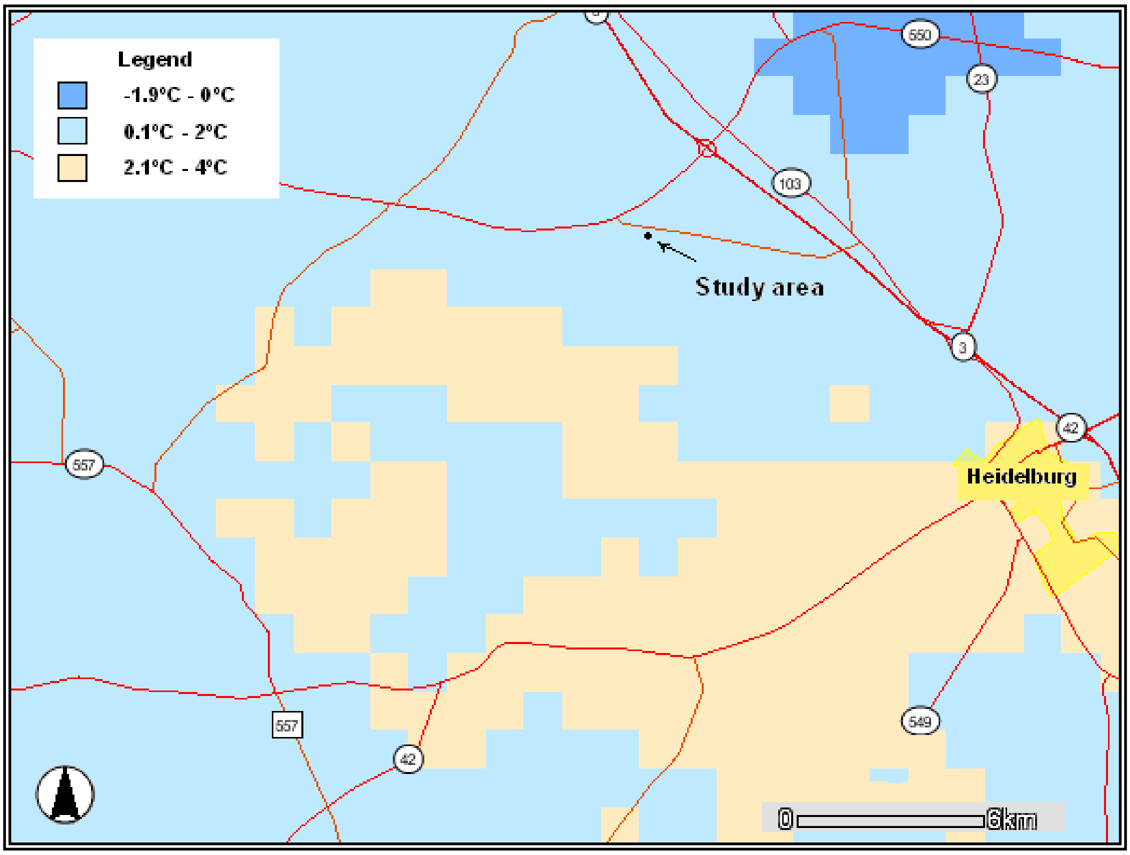


Figure 2.6: Map showing the mean minimum annual temperatures in and around Suikerbosrand Nature Reserve and the study area (AGIS 2007).

Due to the long clear nights, little wind and dry air during the Highveld winter, the occurrence of frost is common. The study area receives 80 to 100 days of frost and about 60 days of heavy frost per annum. Winter atmospheric conditions cause temperature inversions, which have the effect of keeping polluted air close to the surface, causing winter air quality over the Highveld to be generally poor (Schulze & Maharaj 2006).

2.3. Geology

2.3.1. Suikerbosrand Nature Reserve tectonic framework

The reserve lies on the Kaapvaal craton, which is the largest Archean craton in South Africa and comprises most of the northeastern tectonic framework of the country. The Kaapvaal craton is one of the best-preserved Archean cratons known. It is made up largely of Archaean gneisses and granitoids (Basement Complex), along with lesser volumes of metamorphosed, volcanic sedimentary rocks (greenstone belts). The almost continuous record of Archean-paleoproterozoic sedimentation makes the Kaapvaal craton one of the best areas on the globe to research early Earth history (De Wit *et al.* 1992).

Overlaying the Kaapvaal craton, the reserve is situated on two geological sequences, namely the Ventersdorp Supergroup and the Witwatersrand Supergroup, with the latter being the older stratigraphic sequence. Outside the boundaries in the far northern part of the reserve the Transvaal sequence makes its appearance.

2.3.1.1. Ventersdorp Supergroup

The main outcrop of the Ventersdorp Supergroup occurs in an area bounded by Vryburg (Northern Cape), Mafikeng and Ventersdorp (Figure 2.7). A separate cluster of smaller outcrops occurs in an area southeast of Johannesburg. The largest portion of the reserve, mainly the central and northern parts, including the study area, is situated on the Ventersdorp Supergroup.

This geological formation is responsible for smooth hills and ridges with woodland communities at sheltered sites and grassland on exposed high altitude slopes and plateaux (Bredenkamp & Brown 2003). Within the study area the Ventersdorp Supergroup deposited various types of stones, some well preserved and some completely weathered. These include andesitic to dacitic lava, chert, tuff, quartzite and agglomerate. Soil deriving from this geological formation is generally medium textured, often medium to relatively deep (±1.5 m deep) and considered of high

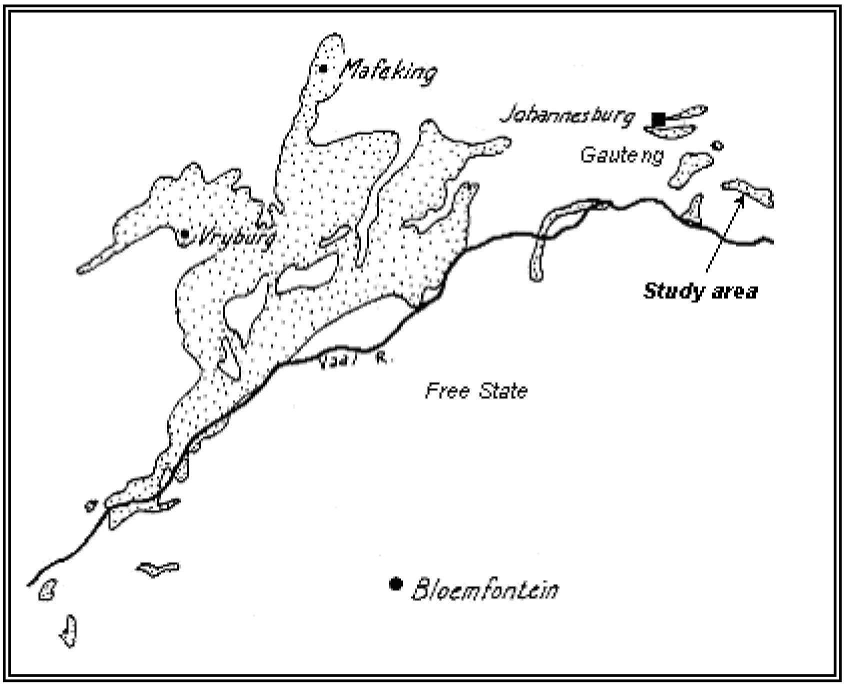


Figure 2.7: Outcrop distribution (dotted area) of the Ventersdorp Supergroup (Lurie 1994), on which the study area is situated (arrow). The black line indicates the Vaal River.

arable value.

2.3.1.2. Witwatersrand Supergroup

As a result of extensive mining and exploratory drilling the lithology and structure of the Witwatersrand Supergroup is reasonably well known, despite the relatively small outcrop areas. The structure of the Witwatersrand Supergroup is essentially that of an elongated basin underlying the Gauteng and northern Free State provinces. The bottom of the basin has been updomed in the Vredefort area (Lurie 1994).

Outcrops and suboutcrops are restricted to the rim of the basin and around the Vredefort dome. There are several large faults in the outcrop area of the Witwatersrand Supergroup (Figure 2.8). Among others, the Sugerbush fault (Figure 2.8), which has a throw of about 5 000 m, is encountered in the Heidelberg area. The Witwatersrand Supergroup has two subdivisions, namely the West Rand Group and the Central Rand Group with the subgroups Johannesburg and Turffontein belonging to the latter group (Lurie 1994).

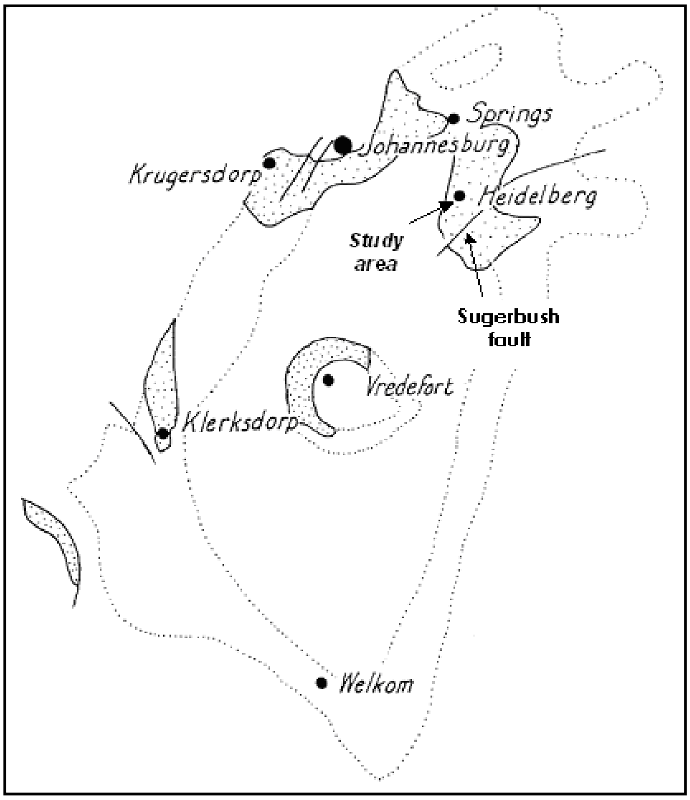


Figure 2.8: The outcrop distribution of the Witwatersrand Supergroup (Lurie 1994), on which the largest part of SNR is situated.

The Witwatersrand Supergroup (Turffontein subgroup), which is exposed in the southern and southeastern part of the reserve, is essentially quartzitic with prominent conglomerate zones. Among the Turffontein subgroup are the Kimberley reefs, which is the only prominent argillaceous horizon in the Central Rand Group (Lurie 1994). The soil deriving from Witwatersrand Supergroup geology varies greatly but is generally shallow, lightly textured and well drained.

2.4. Terrain morphology

The topography and terrain morphology of an area is important as it influence climatic and edaphic conditions, thereby indirectly contributing to microclimatic and biological diversity. The more variety in terrain morphology the more variety in microclimatic and biological diversity and *vice versa.*

To quantitatively describe relief, two procedures have been applied in South Africa, namely the procedure prescribed for Soter Landforms databases (van Engelen & Wen 1995) and the procedure devised for the National Land Type Survey (NLTS) (Macvicar 1985). The procedure followed by the NLTS was devised by Kruger (1973), following Hammond (1964). It quantitatively describes the terrain or relief of an area by means of two parameters, percentage level land and local relief.

According to the Land Type Classification the terrain at the study area is classified as an A3 land type, meaning that (A) more than 80% of the area has slopes less than 8%, and (3) the average difference between the highest and lowest point in the landscape is 90 – 150 m. The terrain at the study area can generally be described as plains with open low hills or ridges.

The same land type survey classifies the more hilly original portion of the reserve as a C4 land type, meaning that only 20 – 50 % of the terrain has slopes of less than

Figure 2.9: Photographic image of the terrain morphology taken from the study area towards the original portion of the reserve in the south. The whole area in view is situated on Ventersdorp Supergroup geology.

8% and that the average difference between the highest and lowest point is 150 – 300 m. Generally the terrain in this portion is described as “open high hills or ridges” (also see Figure 2.9). The terrain of the study area is a multi-phase terrain type and contains crests, midslopes, footslopes and valley bottoms. The study area is situated more or less between a midslope and a foot slope (Figure 2.10).

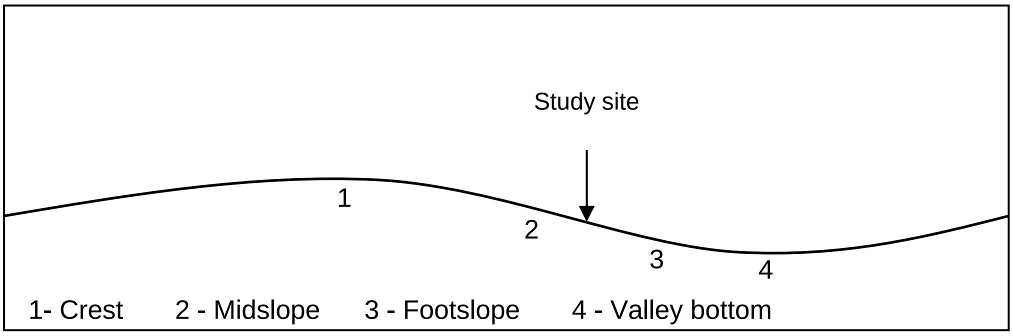


Figure 2.10: Location of the study area in terms of the relief (slope % accentuated).

The more internationally recognised Global Terrain Digital Database, commonly known as Soter Landforms, gives more or less the same description for the two terrain types on the reserve. According to the Soter Landforms the study area is described as “plains at a medium level” and the older portion of the reserve as “medium-gradient hills”.

2.5. Soil

The soil at the study area is generally shallow (150 - 400 mm deep) and, although cultivated in the past, is somewhat marginal for crop production. The depth of soil does not differ significantly between the old cropland and the adjacent natural rangeland. Deriving mainly from andesitic lava, the soil is relatively well textured (± 20% clay) (Table 4.7). According to the taxonomic soil classification system for South African soils, the soil at the study area belongs to the Glenrosa soil type (Soil Classification Working Group 1991). The soil profile consists of an Orthic A horizon, with an organic carbon content of about 1.3%. The Orthic A horizon ends on a Lithocutanic B horizon, which consists mainly of quartzite, chert and concretions of plinthic material. The plinthic material generally has a manganese base, although iron based concretions are present.

2.6. Natural vegetation

2.6.1. General vegetation of the study area

To broadly describe the vegetation of the study area, reference is made to the seminal classification carried out for South Africa, Lesotho and Swaziland, as edited by Mucina & Rutherford (2006). With this system the region was classified into 435 zonal and azonal vegetation types, using a three-level hierarchy of mapping units, namely Biome, Bioregion and Vegetation Unit. In addition to data on vegetation distribution, data sources on topography, geology, soils, land types and climatic zones were also used (Mucina & Rutherford 2006). The five vegetation units occurring in the area (three within the boundaries of SNR) are presented in Table 2.2 and Figure 2.11.

Table 2.2: Vegetation units within the Suikerbosrand Nature Reserve according to Mucina & Rutherford (2006).

Vegetation Unit	Code	Bioregion	Biome
Andesite Mountain Bushveld	SVcb 11	Central Bushveld	Savanna
Gold Reef Mountain Bushveld	SVcb 9	Central Bushveld	Savanna
Tsakane Clay Grassland	Gm 9	Mesic Highveld Grassland	Grassland
Soweto Highveld Grassland	Gm 8	Mesic Highveld Grassland	Grassland
Carletonville Dolomite Grassland	Gh 15	Dry Highveld Grassland	Grassland

The study area, as with most of the new extended portion of the reserve, falls within the Tsakane Clay Grassland. This vegetation unit consists of characteristically flat to slightly undulating plains and low hills. The vegetation is short, dense grassland dominated by a mixture of common highveld grasses such as *Themeda triandra, Heteropogon contortus, Elionurus muticus* and a number of *Eragrostis* species. The most prominent forbs are from the families *Asteraceae*, *Rubiaceae*, *Malvaceae*, *Lamiaceae* and *Fabaceae*. Disturbance in this vegetation unit leads to the increase in the abundance of the grasses *Hyparrhenia hirta* and *Eragrostis chloromelas* (Mucina & Rutherford 2006).

Despite being somewhat dated, Acocks' (1988) vegetation classification into the so-called "Veld Types" remains a scientifically respected and generally accepted seminal work on the natural vegetation of South Africa. According to this classification the vegetation of the Suikerbosrand Nature Reserve is classified as "Bankenveld" (Acocks veld type 61) (Figure 2.12). Acocks (1988) describes Bankenveld as a "False Grassland". The climax vegetation should, according to Acocks, be an open savanna, but it has been changed to, and maintained as open grassland by regular fire. Subsequently, woody species, being more sensitive to fire, are mainly found in protected habitats such as rocky outcrops.

Bankenveld is generally characterised by a complex topography, which includes

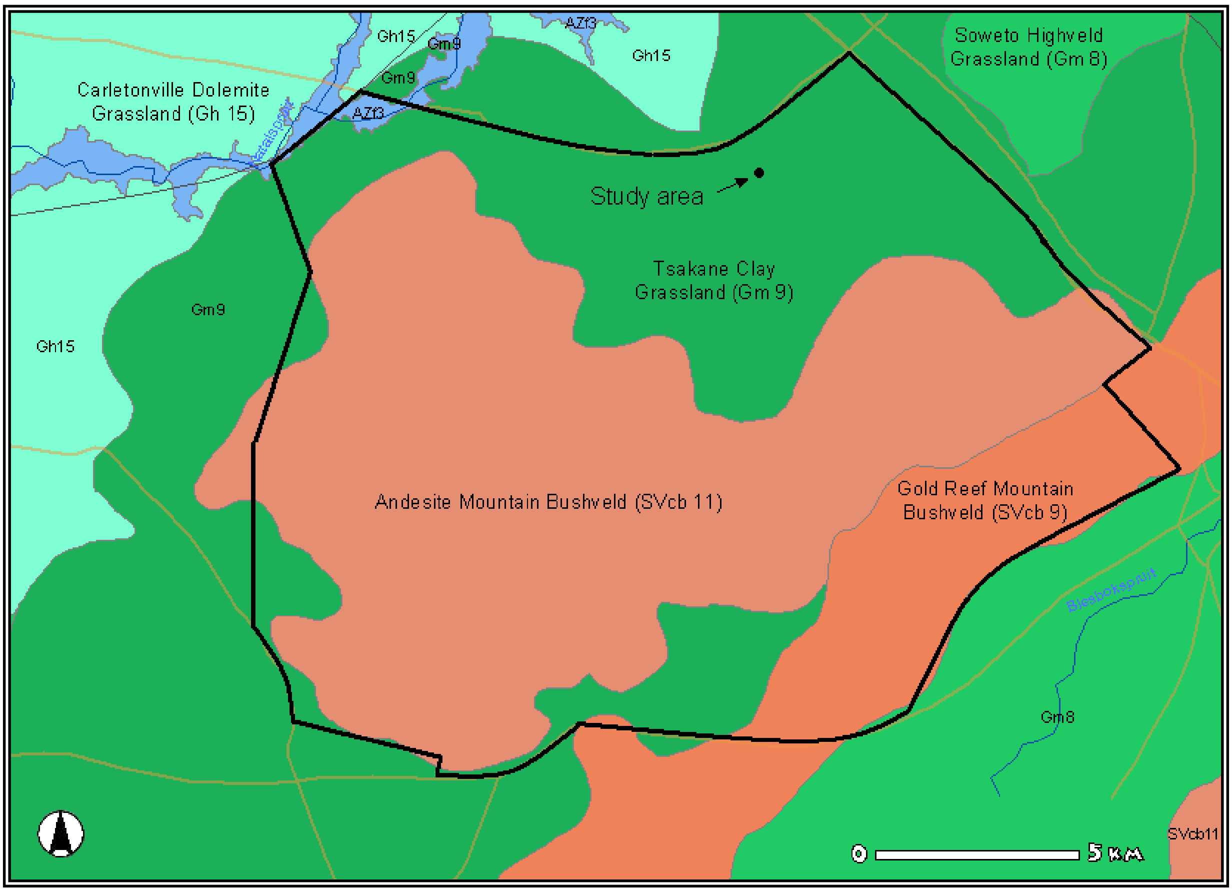


Figure 2.11: Map showing the distribution of vegetation units according to Mucina & Rutherford (2006) on and around Suikerbosrand Nature Reserve (black lined area). Also refer to Table 2.2. for codes and names of vegetation units.

rocky hills, ridges, plateaux and plains. Rockiness of the soil surface is a further common characteristic shared by most Bankenveld areas. Bankenveld occurs as a 60 km (on average) wide east-west stretching belt of almost 400 km, along the 26° S latitude, between 26° and 30° E longitude (Bredenkamp & Brown 2003).

Bankenveld, or Rocky Highveld Grassland, as expressed by Bredenkamp and Van Rooyen (1996), is generally described as moist cool temperate grassland with *Rhus leptodyctya – Acacia caffra* mountain bushveld mixed with *Louditia simplex – Trachypogon spicatus* grassland.

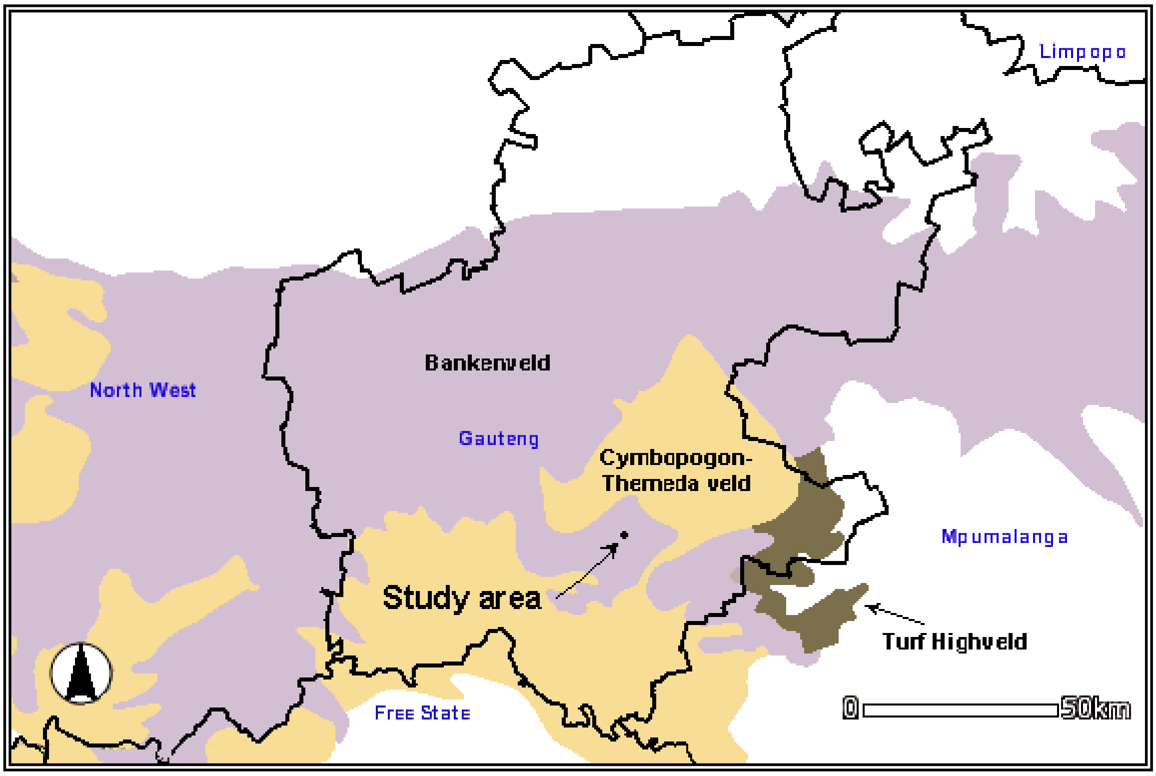


Figure 2.12: Distribution of Bankenveld and *Cymbopogon-Themeda* veld (Acocks 1988) in Gauteng Province in relation to the study area.

The Acocks (1988) interpretation of Bankenveld being a False Grassland (fire origin and maintained by fire) is rejected by Bredenkamp & Van Vuuren (1987), Coetzee *et al.* (1993), O'Connor & Bredenkamp (1997) and Bredenkamp (1999), as there is essentially no difference in the fire regimes of the grassland and savanna biomes. These authors interpret Bankenveld as a mosaic of grassland and woodland communities controlled by (micro-) climatic conditions that exist in the topographically heterogeneous landscape in the transition zone between these two biomes. Woodland communities occur on relatively warm sites in sheltered valleys and on slopes while grassland communities (where the study area is located) occur on relatively cold, exposed high altitude plateaux and plains (Bredenkamp & Brown 2003).

Although the separation on a structural basis between grassland and savanna is ecologically sound, close floristic relationships exist between certain grassland and savanna communities that occur on similar geological substrates (Werger & Coetzee 1978). Therefore, being a transitional area between the grassland and savanna biomes, it is evident that both these biomes contribute to the floristic makeup of the Bankenveld (Bredenkamp & Brown 2003).

Dryland crop production is limited in the Bankenveld due to the shallow, rocky soils. However, open grassland areas within Bankenveld are often extensively cultivated. Grazing by cattle is often found in this vegetation type, but the dominance of sour grass species often results in a low nutrient status of the grass, particularly during winter (Morris 1976).

2.6.2. Floristic Vegetation Units

Bredenkamp & Brown (2003) have described sixteen floristic vegetation units within the Bankenveld. Two of these units, *Cymbopogon plurinodis-Themeda triandra* Grassland and *Hyparrhenia hirta* Anthropogenic Grassland, occur in the study area. These vegetation units are described below in terms of habitat and vegetation:

2.6.2.1. Cymbopogon plurinodis-Themeda triandra Grassland

Location and habitat

Patches of the *Cymbopogon plurinodis-Themeda triandra* Grassland are distributed throughout the Bankenveld, though it occurs more extensively in the southern (Potchefstroom, Johannesburg and Heidelberg) and southeastern (south of Witbank and Middelburg) parts, where it is present on flat or undulating plains with deep soils. Although mapped as Bankenveld, these *Themeda*-dominated grasslands rather represent Acocks' (1988) *Cymbopogon-Themeda* Veld (48). These grasslands are relatively poor in plant species, though, due to the arable soils, much has been destroyed for agricultural purposes. This type of grassland is very widely distributed in the highveld region of South Africa (O'Connor & Bredenkamp 1997).

Vegetation

The most diagnostic grass species in this grassland are *Cymbopogon plurinodis* and *Trichoneura grandiglumis.* Although there are many forbs, they are never dominant and are mostly inconspicuous and hidden in the dense grass layer. Of these *Helichrysum miconiifolium, Anthospermum hispidulum, Acalypha angustata, Ipomoea crassipes, Hermannia depressa* and the geophyte *Hypoxis hemerocallidea* are the most prominent. The dominant grass is mostly *Themeda triandra*, with *Eragrostis curvula, Heteropogon contortus, Setaria sphacelata* and *Aristida congesta* also common.

Plant communities in this type of grassland within the Bankenveld area were described by *inter alia* Bredenkamp *et al.* (1989), Bredenkamp & Theron (1980), Bezuidenhout & Bredenkamp (1991), Bezuidenhout *et al.* (1994a), Coetzee *et al.* (1995). Several phytosociological studies of similar *Cymbopogon plurinodis-Themeda triandra* Grasslands from outside the Bankenveld, emphasise the affinity to Acocks' (1988) *Cymbopogon-Themeda* Grassland (Kooij *et al.* 1992, Smit *et al.* 1992, Eckhardt *et al.* 1996, Fuls *et al.* 1993).

This grassland vegetation unit (*Cymbopogon plurinodis-Themeda triandra* Grassland), as described by Bredenkamp & Brown (2003), probably best describes the natural grassland from the study area.

2.6.2.2. *Hyparrhenia hirta* Anthropogenic Grassland

Locality and habitat

This tall grassland occurs over vast areas, usually on shallow, leached soils on the Johannesburg granite dome, and on undulating north-facing warm andesitic lava slopes of the Suikerbosrand, Witwatersrand and Klipriviersberg areas. Disturbed grassland or other disturbed areas such as road reserves or old fields, not cultivated for some years, are also usually *Hyparrhenia*-dominated. Although some of these tall grasslands appear to be quite natural, they are mostly associated with an anthropogenic influence from recent or even iron-age times. Very often "natural" *Hyparrhenia*-dominated grasslands occur on ancient cultivated areas in the Central Variation of the Bankenveld (Acocks 1988) and in the surroundings of archaeological sites (Brown & Bredenkamp 2002), where the inhabitants had a mosaic of cultivated lands and grazing of domestic stock. It seems that these degraded sites developed into to a *Hyparrhenia*-dominated grassland, which tends to be stable for a very long time. In a study on secondary succession of old croplands, by Roux & Warren

(1963), it was found that *Hyparrhenia hirta* could dominate disturbed grassland for more than fifty years.

Bredenkamp & Brown (1998) found a few relic sites that indicate that the original vegetation on the shallow granitic soils of the Johannesburg Dome could have been a variant of the *Monocymbium ceressiforme-Loudetia simplex* Grassland. *Hyparrhenia*-dominated tall grasslands are also widely distributed in the midland areas of KwaZulu-Natal (Moll 1965) and the northern parts of the Eastern Cape (former Transkei area) (Smits *et al.* 1999), where former and present land-uses enhance the prominence of *Hyparrhenia hirta* (McKenzie 1984).

Vegetation

This grassland is characterised by the tall growing dominant grass *Hyparrhenia hirta* and the invader dwarf shrub *Seriphium plumosum*, indicating its low successional status or degraded condition.

Hyparrhenia-dominated grassland mostly has low species richness, with only a few other species able to establish or survive in the shade of the dense sward of tall grass. Most of these species are relict pioneers or early successional species. The most prominent species include the grasses *Cynodon dactylon*, *Eragrostis plana*, *E. racemosa*, *E. curvula* and *Aristida congesta*. Forbs are rarely encountered, though a few individuals of species such as *Anthospermum rigidum, Conyza podocephala, Crabbea angustifolia* and *Helichrysum rugulosum* are often present.

Examples of this type of grassland in the Bankenveld were described from the Jack Scott Nature Reserve (Coetzee 1975), Suikerbosrand Nature Reserve (Bredenkamp & Theron 1980), the eastern Bankenveld from the Pretoria-Heidelberg-Witbank area (Coetzee *et al.* 1995), Witbank Nature Reserve (Smit *et al.* 1997), Boskop Dam Nature Reserve (Bredenkamp *et al.* 1994) and from the Lichtenburg area (Bezuidenhout *et al.* 1994b).

This grassland type is common on old lands and other disturbed areas in the new extended portion of the SNR. Below follows a more detailed description of vegetation within the SNR, with emphasis on the new extended portion.

2.6.3. Specific vegetation at the study area

The vegetation for both the formerly cultivated lands and the natural rangeland next to the study area were recorded prior to the establishment of the trials. As to be expected, the vegetation differs dramatically between the two areas due to the impact of cultivation on the natural seed bank and of soil properties.

2.6.3.1. Vegetation in natural rangeland near the study area

Detailed vegetation classification and phytosociological studies were carried out for the original reserve by Bredenkamp (1975) and Panagos (1999) respectively. Panagos (1999), based on the original study concluded by Bredenkamp (1975), identified seven different vegetation communities within the original reserve. A similar but more recent study was conducted in natural rangelands of the new extension (where the study area is situated) by Hoare (2006). Through these studies detailed vegetation maps were produced by Panagos (1999) and Hoare (2006). Below are the seven plant communities identified by Panagos (1999):

Suikerbosrand Nature Reserve Plant Communities (Panagos 1999)

1. *Seriphium plumosum - Eragrostis plana* short closed grassland on grazed patches and old lands.
2. *Harpochloa falx - Indigofera hedyantha* short closed grassland on the high plateau.
3. *Cussonia paniculata* subsp. *paniculata - Hermannia grandistipula* short open shrubland on North-facing slopes.
4. *Acacia caffra - Ehrharta erecta var. natalensis* short closed woodland in South-facing kloofs.
5. *Acacia karroo - Panicum maximum* low open woodland on old lands and burned *Acacia*-veld.
6. *Leucosidea sericea - Setaria sphacelata* var. *sericea* tall closed grassland in standing water.
7. *Englerophytum magalismontanum - Aristida transvaalensis* tall closed shrubland on the

A total of 302 species and infra-specific taxa were recorded in the seven plant communities during this survey. Many of these were recorded in the original survey by Panagos (1999), indicating the overall floristic similarity of the two areas, but 52 species are new records for the reserve (Hoare 2006). The plant communities identified in the classification of the data for the new extended portion of the reserve fall within the same seven plant communities identified within the original reserve area by Panagos (1999). However, two communities, Community 4 (*Acacia caffra-Ehrharta erecta* var. *natalensis* short closed woodland) and Community 5 (*Acacia karroo-Panicum maximum* low open woodland) do not occur in the new extension. The plant communities' distributions are presented in the form of a vegetation map for the reserve (Figure 2.13).

The main vegetation community in areas near the study area, as described by Panagos (1999), is *Seriphium plumosum - Eragrostis plana* short closed grassland on grazed patches and old lands. This vegetation community shows much resemblance, in terms of species present, to the broader vegetation unit described by Bredenkamp & Brown (2003) as *Hyparrhenia hirta* Anthropogenic Grassland. The dominant species in terms of frequency and cover are presented in Table 2.3.

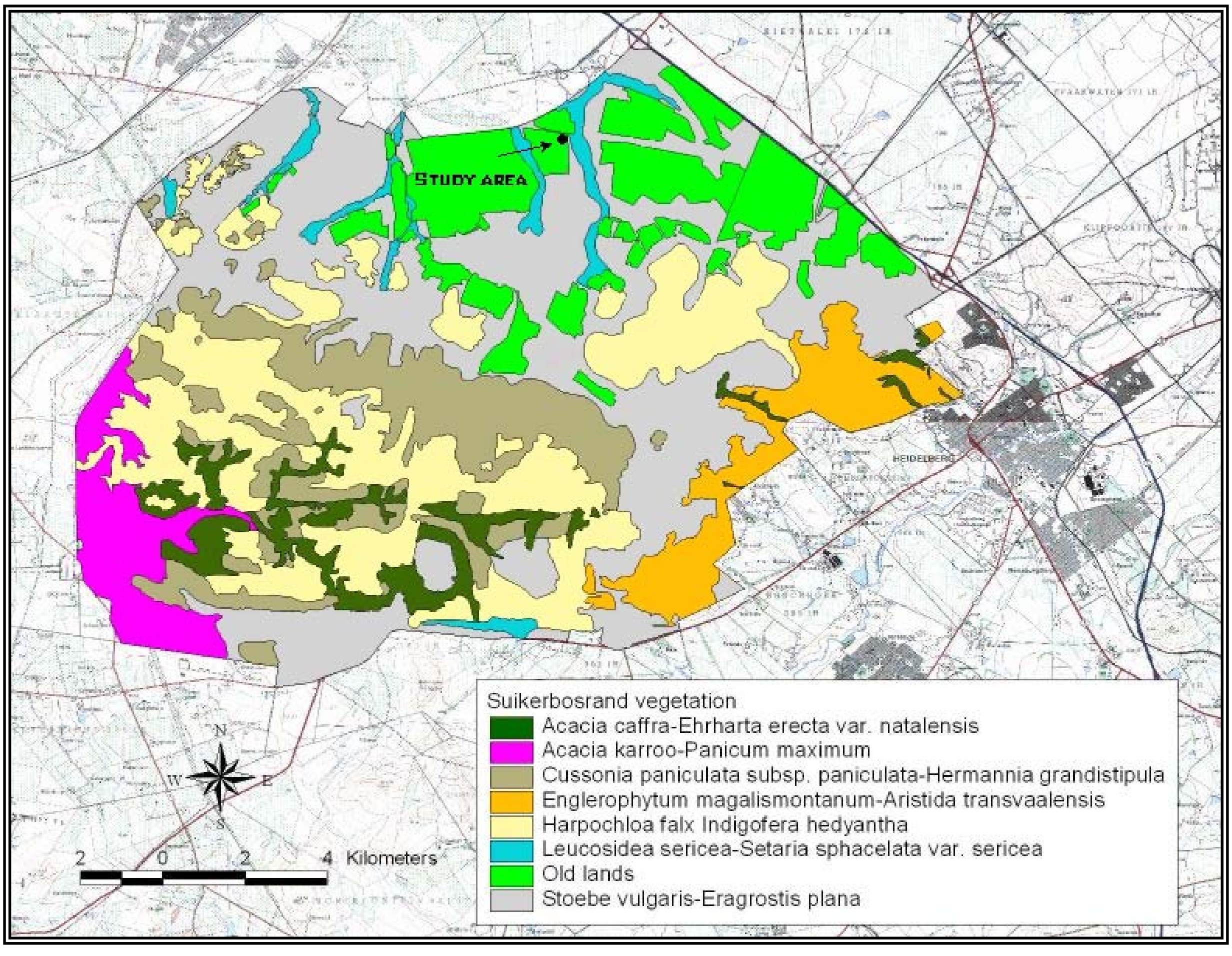


Figure 2.13: The distribution of the 7 vegetation communities in the Suikerbosrand Nature Reserve as compiled by Panagos (1999) and Hoare (2006).

Table 2.3: Species cover relations, growth form and competition status of main species in the *Seriphium plumosum - Eragrostis plana* vegetation community in Suikerbosrand Nature Reserve (Panagos, 1999).

Species	Growth form	Competition status	Canopy cover (%)	Crown diameter (m)	Plant density (ind/m^2)
Eragrostis chloromelas	Grass	Strong	4.8	0.12	4
Hyparrhenia hirta	Grass	Strong	5.4	0.12	4
Setaria sphacelata	Grass	Normal	1.4	0.07	4
Helichrysum rugulosum	Forb	Strong	1.4	0.07	3
Themeda triandra	Grass	Normal	2.4	0.11	3
Heteropogon contortus	Grass	Normal	1.8	0.09	3
Trachypogon spicatus	Grass	Normal	2	0.13	1
Elionurus muticus	Grass	Normal	1	0.12	1
Eragrostis curvula	Grass	Normal	1.5	0.16	1
Hyparrhenia dregeana	Grass	Strong	2.3	0.33	0
Seriphium plumosum	Dwarf shrub	Strong	1.9	0.6	0
				Total	**24**

The total canopy cover for the vegetation community, determined by Panagos (1999), is 43% and that of the woody component (mostly *Seriphium plumosum*) is low at 6.4%. No plant density (ind/m^2) data is available. This community is situated in the northwestern corner of the SNR and in a belt running from the northeastern corner
through to the south-western corner. It is differentiated from the other six communities in the study area on the basis that it occurs below 1700 m above sea level (m.a.s.l.) on flats predominantly consisting of old lands and grazed grassland, with no surface rock and a median slope of 2º.

During the survey of Hoare (2006) in the new extension, plant species composition was recorded through a belt transect at twenty-six sample sites. Fortunately one of these transects (site 108 at coordinates 26°26’2.6”S and 28°15’57.6”E) was done in undisturbed grassland near the study area and revealed the following species composition (Table 2.4) on 23 February 2006. This site, with its species composition, was used in this study as a reference ecosystem.

Table 2.4: Species list of most common plants in natural rangeland near the study area (Hoare 2006), arranged top-down according to abundance.

Nr.	Species	Growth form	Family
1	*Setaria sphacelata*	Grass	Poaceae
2	*Themeda triandra*	Grass	Poaceae
3	*Elionurus muticus*	Grass	Poaceae
4	*Brachiaria serrata*	Grass	Poaceae
5	*Acalypha caperonioides*	Forb	Euphorbiaceae
6	*Helichrysum rugulosum*	Forb	Asteraceae
7	*Trachypogon spicatus*	Grass	Poaceae
8	*Diheteropogon amplectens*	Grass	Poaceae
9	*Eragrostis chloromelas*	Grass	Poaceae
10	*Eragrostis curvula*	Grass	Poaceae
11	*Eragrostis racemosa*	Grass	Poaceae
12	*Bewsia biflora*	Grass	Poaceae
13	*Cymbopogon excavatus*	Grass	Poaceae
14	*Hypoxis iridifolia (multiceps)*	Forb	Hypoxidaceae
15	*Pentanisia angustifolia*	Forb	Rubiaceae
16	*Senecio species*	Forb	Asteraceae
17	*Ziziphus zeyheriana*	Dwarf shrub	Rhamnaceae

2.6.3.2. Vegetation on formerly cultivated lands (study site)

The data below was collected by visually assessing a 10 m x 10 m plot in the centre of the study area directly prior to establishment of the trials. This specific land was still under maize cultivation the season (2002/03) before the trials were established (February 2004). Vegetation cover was assessed as follows:

Broadleaf weed cover	60%	
Grass weed cover	5%	
Open Ground	35%	(with some crop residue present (Figure 2.14))

Figure 2.14: Photographic image of study area prior to establishing the trials, showing the poor plant cover and previous season crop residue.

As to be expected, the species present were all cropland weeds that are typical to the Highveld region. The weed species recorded were (arranged top-down from most common to less common):

Grasses	Forbs (broadleaf weeds)	Sedges
Urochloa panicoides	*Datura stramonium*	*Cyperus esculentus*
Eleusine coracana	*Amaranthus hybridus*	
Panicum schinzii	*Tagetus minuta*	
Chloris virgata	*Portulaca oleracea*	
Zea mays	*Sisymbrium thellungii*	
	Cleome monophylla	
	Hybiscus trionum	
	Hybiscus trionum	

2.7. Former management practices

During an interview with the previous land user, to obtain information about previous management practices, the following information was gathered:

The formerly cultivated croplands in the study area (Figure 2.14) were exclusively used for annual crop production for at least 15 years prior to establishment of the trials. The last season the study area was used for crop production was during the 2002/03 season when maize was produced. The main crops produced were maize rotated with sunflower about every four years. According to the previous owner, good care was taken to prevent mineral exhaustion of the soil where the policy was rather to build up the mineral assets of the soil. To counter for the acidification effect of nitrification on soil pH, dolomitic lime was applied (based on a prior soil analysis) at a sequence of about every four years. These practices are evident when comparing the soil analysis of the cultivated lands with that of the adjacent rangeland (see Table 4.7).

In most instances cultivation was carried out through tilling with a mould board plough and levelling with a disc plough. No conservation tillage methods, such as no-till or minimum till, were used. Although slopes are rather level and generally less than 4º, the farmer cultivated along the contour, thereby decreasing the risk of excessive runoff and subsequent soil loss through erosion.

2.8. Summary of environmental attributes

The table below (Table 2.5) summarises the main environmental factors influencing, directly and indirectly, the ecology at the study area. From the table can be seen that the elevation is relatively high, which are causing cold, frost prone winters. Together with the terrain, which is open and don not providing protection for woody species against frost, and frequent fires, these factors are causing open grassland conditions to prevail.

The soil in the study area, deriving from Andesitic lava, is relatively well textured and therefore popular for cropping. Although the soil depth at the study area is shallow (Table 2.5), it is deeper and more arable in other nearby areas.

Table 2.5: Main environmental attributes and parameters for the study area within the new extended portion of the Suikerbosrand Nature Reserve.

Summary of Environmental Attributes and Parameters	
Factor	**Value**
Location	South east Gauteng, South Africa
Geographical coordinates	26°26'20.11" S & 28°15'35.57" E
Elevation	1 575 m.a.s.l.
Climate	Temperate - moist and cool
Mean annual temperature	16ºC
Mean annual rainfall	± 600 mm/annum
Tectonic framework	Kaapvaal
Terrain	Undulating plains and low hills
Geographical sequence	Ventersdorp Supergroup
Soil origin	Andesitic lava
Soil texture	20 % clay
Soil depth	150 mm – 400 mm
Biome	Grassland
Bioregion	Mesic Highveld Grassland
Vegetation Unit	Tsakane Clay Grassland (Bm 9)
Dominant plant families in rangeland	Poaceae, Asteraceae

CHAPTER 3
MATERIALS AND METHODS

The study site is located on the verge of a cropland that was cultivated the previous season (2002/03) (Figure 3.1). During site selection, care was taken to include the whole site within the same aspect and slope gradient as well as the same general soil type. The various restoration trials were established during early February 2004.

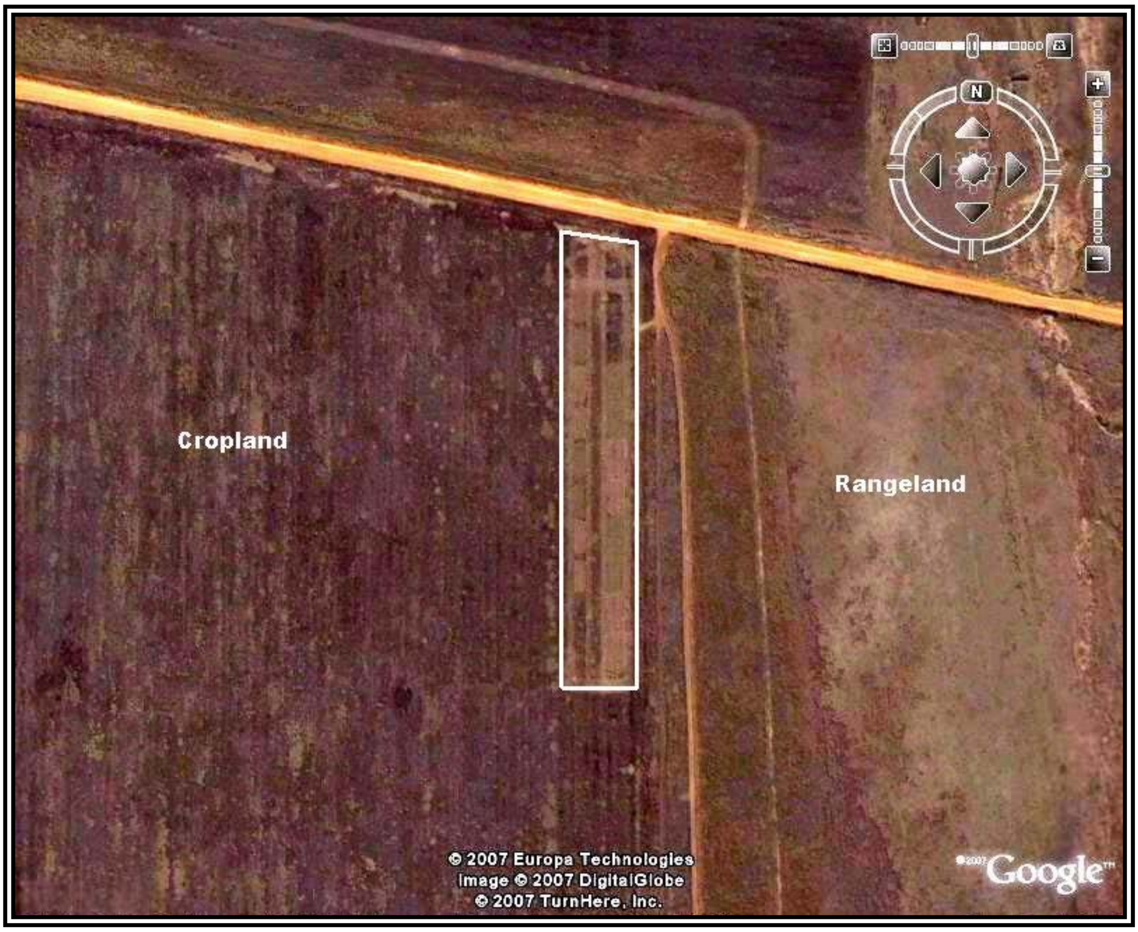


Figure 3.1: Satellite image of the actual experimental block, showing the proximity of the site in terms of the cropland, rangeland and roads.

3.1. Experimental design

In total, twenty 200 m² (20 m x 10 m) plots, arranged in two rows with 5-meter buffer zones between each, were established (Figure 3.2). Buffer zones between the plots were slashed during the growing season to prevent seed transfer to adjacent plots and to make plot recognition easier. No fencing material was used and the study site was not enclosed (no grazing animals were present). The total size of the experimental block was about 250 m x 50 m (Figure 3.2).

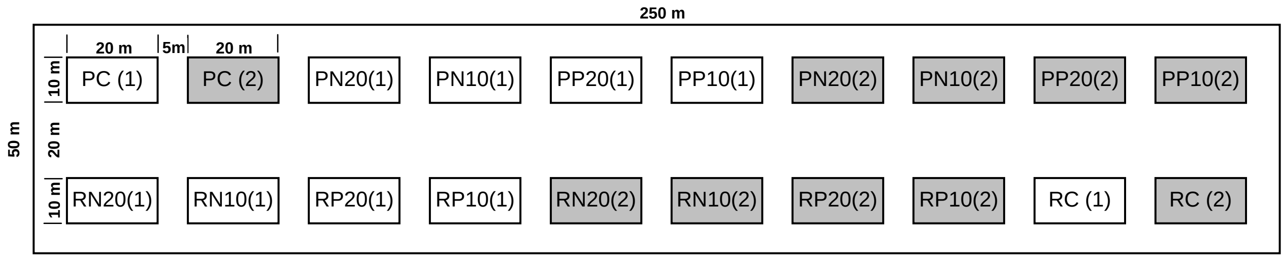


Figure 3.2: The experimental site design, showing the plot layout and the treatment codes (see Table 3.1 for code explanation of treatments). The shaded boxes indicate the position of the 2^{nd} replicates.

In an attempt to share and equalize error, plots were situated on the same soil gradient with replicates at least 80 metres apart (except for the control plots). Furthermore, since it was partly row planted treatments, the longitudinal design of the plots extends the length of the research block and thereby increases the precision of the experiment (Snedecor & Cochran 1980).

Table 3.1: The different combined treatments applied in the study.

Treatment Nr.	Sowing Method	Grass Seed Mixture	Seeding Rate	Treatment Code
1	Plough Method	Natural Grass Mixture	10 kg/ha	PN10
2	Plough Method	Natural Grass Mixture	20 kg/ha	PN20
3	Plough Method	Pasture Grass Mixture	10 kg/ha	PP10
4	Plough Method	Pasture Grass Mixture	20 kg/ha	PP20
5 (Control)	Plough Method		No seeding	PC
6	Ripper Method	Natural Grass Mixture	10 kg/ha	RN10
7	Ripper Method	Natural Grass Mixture	20 kg/ha	RN20
8	Ripper Method	Pasture Grass Mixture	10 kg/ha	RP10
9	Ripper Method	Pasture Grass Mixture	20 kg/ha	RP20
10 (Control)	Ripper Method		No seeding	RC

3.2. Treatments

A total of eight different reseeding treatments (excluding control treatments) were used in the experiment. These treatments consisted of a combination of two site preparation methods, two seed mixtures and two seeding densities (Table 3.1).

3.2.1 Seed mixtures

Experimental studies have found that increasing species diversity reduces community invasion by weeds and invasive species (Tilman 1997, Naeem *et al*. 2000). Therefore, in this study the aim was to re-introduce various local grasses, which should act as a starting point on the road to recovery. As far as possible, grasses local to the immediate locality have been selected, as these species should compete well under local climatic and edaphic conditions.

Two different seed mixtures were used in the study. Because the natural grassland is dominated by C_4 grasses, these two mixtures consisted of five natural C_4 grass species each. The one mixture contained five local natural grass species and the other five commercial pasture grasses. Below is a list of the selected grass species used in the trials:

Natural grass mixture:	Pasture mixture:
Heteropogon contortus	*Cenchrus ciliaris – cv. Molopo*
Melinis repens	*Cynodon dactylon – cv. Common Bermuda*
Eragrostis chloromelas	*Eragrostis curvula – cv. Ermelo*
Eragrostis curvula	*Digitaria eriantha – cv. Irene*
Cenchrus ciliaris	*Panicum maximum – cv. Gatton*

During the selection of suitable accessions to be included in the list above, two aspects (other than distribution) were considered. These are:

- Successional status of species
- Availability of seed

3.2.1.1. Successional status of seed mixture species

Because early-succession species, such as agricultural weeds, are adapted to high levels of available natural resources, particularly moisture and light (Baker 1965, Chapin 1980), they may be unlikely to invade resource-poor plant communities such as competitive late successional communities. Observational studies have found fewer annual and perennial invaders in late- than in early-succession plant communities (Rejmanek 1989), such as recently abandoned croplands. Therefore, diverse, late-succession local plant communities may be more resilient to invasion by common weeds and invader species (Blumenthal *et al.* 2003). For this reason mainly late-successional grasses were used in the mixtures, as these species are more competitive.

3.2.1.2. Availability of seed

In a small-scale trial such as this it is important to consider species of which the seed is generally available, particularly if subsequent large-scale restoration is premeditated. However, the availability of natural grass seed, and in particular forb seed, is generally limited in South Africa and the luxury of choice is more than often partial. On the other hand, southern Africa has a relatively wide selection of indigenous cultivated pasture grasses of which the seed is readily available from commercial seed companies.

For this study natural grass seed was obtained from an ecological rehabilitation company[1], which deals mainly with the rehabilitation of mined areas. Although seed of some common local grass species were available, some species, such as the widespread and important grazing grass *Themeda triandra*, was not available during the time of trial establishment, and could therefore not be included. No natural forb or legume seed could be obtained either. For the cultivated pasture mixture, although the choice of species was more limited, all seed were available in large quantities.

[1] EKO REHAB, PO Box 19752, Noordbrug, 2522

3.2.2. Seeding rates

The two seed mixtures were sown at seeding rates of 10 kg/ha and 20 kg/ha respectively. The seed for each mixture was premixed in equal amounts in weight. For one plot (200 m²) at a seeding rate of 10 kg/ha, the total amount of seed required to be sown was 200 g. The 200 g seed was then divided by five for the five species in the mixture, which equals to 40 g per species. Therefore, for each species, at a seeding rate of 10 kg/ha, 40 g seed was sown per plot (see calculation below). For the 20 kg/ha seeding rate, the amount of seed necessary for each species was 80 g per plot.

Example:

10 kg seed/ha	=	10 000 g seed/10 000 m²
10 000 g seed/10 000 m²	=	1 g seed/m²
1 g seed x 200 m² plot	=	200 g seed/plot
200 g seed/5 species	=	40 g seed/species

The somewhat high alternative seeding rate of 20 kg/ha was chosen as a treatment specifically to achieve a dense plant population in order to test resistance towards the highly invasive grass *Hyparrhenia hirta*, which is one of the objectives of this study (also see section 2.6.2.2. *Hyparrhenia hirta* Anthropogenic Grassland).

3.2.3. Site preparation

The aim of site preparation is to prepare a seedbed through cultivation in order to facilitate and enhance the germination of sown species. Site preparation, depending on the method, can also be used to control weed species in the same fashion as with conventional tillage during crop production. For soil preparation during this study, each of the two seed mixtures was established by using two methods, namely the ripper line and the conventional ploughing methods.

3.2.3.1. Ripper method

During the ripper method a one-tooth ripping implement was pulled by a tractor to rip a single line (approximately 150 mm deep) along the length of the plot. The seed was then sown on both sides of the ripped line (Figure 3.3). After turning and ripping the next line, the hind wheel of the tractor was used to cover the seed of the previous line. The lines were about 1 meter apart and there were 9 rip lines in each plot.

Figure 3.3: Establishment of the trials using the ripper method.

3.2.3.2. Plough method

During this method the soil was ploughed (using a three furrow mouldboard plough) and levelled (using a disc plough) to prepare an even seedbed. The seed mixture was then evenly broadcasted by hand over the whole plot area. After broadcasting, the tractor was used to drive over the area to partially cover (Figure 3.4) the seed and thereby improving the soil:seed contact.

Figure 3.4: Covering of seed during the plough method.

Each person involved with hand-sowing the seed was provided with pre-mixed and pre-weighed seed bags. The seed mixtures were continually mixed while sowing and the people were instructed to ensure that the mixtures were evenly distributed over the total plot area.

3.2.3.3. Weed control

Weedy species were not controlled with herbicides before establishment, as these species may be useful pioneers, particularly during the first season. Secondly, herbicides were not used because the residual effect of herbicides on potential new entrant species during secondary succession is unclear. Herbicides would also add extra cost, which might be high in large-scale operations and render future restoration projects thus unfeasible.

3.2.4. Soil analysis and fertilisation

To determine the need for fertilisation during trial establishment, soil analyses were carried out for the cropland and adjacent natural rangeland. Ten soil samples (0 – 150 mm deep) were taken in each area by using a soil auger. The two sets of ten soil samples were then each pooled and well mixed to get a composite soil sample. Each sample weighed about two kilograms. The samples were then spread on stainless steel trays and dried at room temperature while protected from direct sunlight. The two soil samples were then screened through a 2 mm sieve. The remaining material was crushed in a mortar and pestle until it could pass through the 2 mm sieve. Stones were discarded. The soil was then mixed again in a container by turning the container end over end several times. The samples were then separated into smaller samples to undergo Bray 1 (Phosphate (P)), Ammonium Acetate (Calcium (Ca), Manganese (Mg), Potassium (K) and Sodium (Na)), Hydrometer (Fractions) and Walkley Black (Organic carbon) tests. The analyses were carried out by the ARC - Institute for Soil, Climate and Water [2], in Pretoria, and presented in Table 4.7.

3.2.4.1. Fertilisation during trial establishment

No fertilizers were applied before or during establishment of the trials as the comparative soil analysis between the old lands (study site) and natural rangeland ("ecosystem of reference") doesn't suggest any drastic amendments to soil at the study site. It is also generally established that there is lower species diversity with increasing nutrient availability (Tilman 1984, Carson & Barrett 1988, Wilson & Shay 1990, Collins & Wein 1998, Foster & Gross 1998) and that reduced Nitrogen (N) treatments produce a higher degree of community similarity to native grassland than enriched N treatments (Baer *et al.* 2004). It is also mentioned that classic climax grassland on the Highveld of South Africa is understood to exist on dystrophic soils and that climax grasses are regarded to be competitive under conditions of soil nutrient scarcity (Roux 1969, Grossman & Cresswell 1974).

3.2.5. Seed germination and purity test

The species density data indicated that the *Eragrostis chloromelas* seed was contaminated with the close related *Eragrostis plana*. To verify this, the particular seed was sown in two 30 cm x 20 cm x 10 mm seed trays and allowed to grow until separation of the two species were possible. Before sowing the seed in the trays, the medium (pure sand) was micro-waved for 5 minutes for sterilisation. *Eragrostis plana* can easily be distinguished from *Eragrostis chloromelas* by the extremely flattened basal leaf sheaths of the former species (van Oudtshoorn 1999).

[2] ARC – Institute for Soil, Climate and Water. Private Bag X79, Pretoria, 0001

3.3. Vegetation sampling

3.3.1. Sampling layout

A stratified sampling method was used by taking samples uniformly across each plot (Snedecor & Cochran 1980). Eight 1m² quadrates were placed four metres apart in each plot (Figure 3.5). A side clearing distance of four meters in the length and three meters in the width were maintained to prevent any edge effect influencing the data. Each quadrate was further divided into four 0.25 m² squares to assist with counting individual plants.

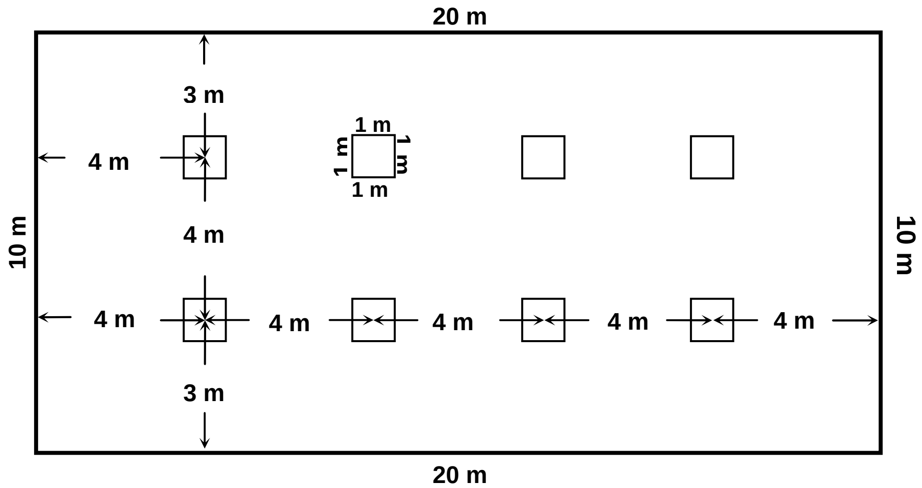


Figure 3.5: The arrangement of quadrates in a single plot during collection of data. The same sampling layout was followed for all 20 plots.

Students from University of South Africa (UNISA) and Endangered Wildlife Trust (EWT) were trained and used for all surveys. Pre-compiled templates were used during the surveys. The data was manually transferred to a Microsoft Excel spreadsheet after each survey.

3.3.2. Seedling emergence

The first data to be collected with the above-described sampling method was seedling emergence data. This information was collected towards the end of the growing season (31 March 2004), eight weeks after establishment of the trials. The seedlings were separated into two groups, namely grasses and forbs (herbaceous flowering plants). Because of the difficulty of identifying the seedlings at this early stage, especially the grasses, the weed grasses and introduced grasses were counted together and regarded to be similar.

3.3.3. Species density

Species density data was collected for two consecutive seasons (2004/05 and 2005/06) after establishment of the trials. This was carried out towards the end of the growing season (March 2005 and March 2006) when species identification was optimal. All individual plants within each 1 x 1 m quadrate were identified and their numbers recorded. A distinction was made between vegetative and reproductive plants.

Throughout the study, specimens of plant taxa unknown at the time of sampling were collected for later identification. For all plant species nomenclature the National Herbarium checklist, as described in Germishuizen & Meyer (2003) was used.

3.3.4. Aboveground phytomass

For this data all aboveground phytomass was cut (about 1 cm above soil surface) in four of the eight quadrates in all twenty plots during the last two recording seasons (2004/05 and 2005/06). The phytomass was collected during March each year when phytomass production was at its highest. Phytomass was collected at different quadrates each year to prevent any effect that might occur by cutting the same area in consecutive years. The phytomass was collected in paper bags and dried for 48 hours at 75 ^{o}C to reach constant mass. After being dried, the grasses and forbs in the samples were separated and weighed with a sensitive spring balance.

3.4. Management of the study site

The trials were not, intentionally or accidentally, subjected to any burning or grazing during the research period. This was specifically planned in order to prevent any negative influence that might be caused by fire on the newly established grasses or selective overgrazing on the more palatable plots.

3.5. Financial records

This study also aimed to contribute to basic financial information and establishing cost on cropland restoration methods. For this a financial analysis for the various treatments was carried out. Cultivation cost was determined by using a costing model for arable farming enterprises developed by the ARC - Institute for Agricultural

Engineering[3] (see Appendix B for input cost). Labour cost was based on the minimum wage of R992.00 per month for rural areas as released by the Department of Labour in February 2006. The financial analysis is given in chapter four.

3.6. Photographic monitoring

To visually portray the various treatments, and to substantiate vegetation data, a set of photographs was taken of each plot, during March, for the two-year study period (see Figures 4.9 to 4.18). An attempt was made to take these photographs from the same position and at the same angle throughout.

3.7. Data analyses

The data was subjected to Analysis of Variance (ANOVA) by the ARC - Biometry Section[3] using the statistical program GenStat (2003). The results were used to test for differences between the various treatments. Treatment means were separated using Fishers' protected t-test least significant difference (LSD) at the 5 % level of significance (Snedecor & Cochran 1980).

Furthermore, multivariate data analyses, using ordination methods with the software Canoco for Windows 4.5 and CanoDraw 4.13 were employed to explore relationships between the different treatments in terms of species abundance within the data set. Best correlation results (between samples and species) were achieved by using the unconstrained method of Principle Component Analysis (PCA) (Ter Braak 1986, 1987). The Monte Carlo test was used to test for significance of canonical correlations.

[3] ARC - Institute for Agricultural Engineering, Private Bag X519, Silverton 0127

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Seedling emergence

Rainfall for the three months (February, March and April 2004) after establishment of the trials were 194, 132 and 33 mm respectively, a total of 359 mm. This total is significantly higher than the long-term average rainfall of 233 mm for the same three months. These favourable conditions resulted in exceptionally good seedling emergence and establishment of the various trials.

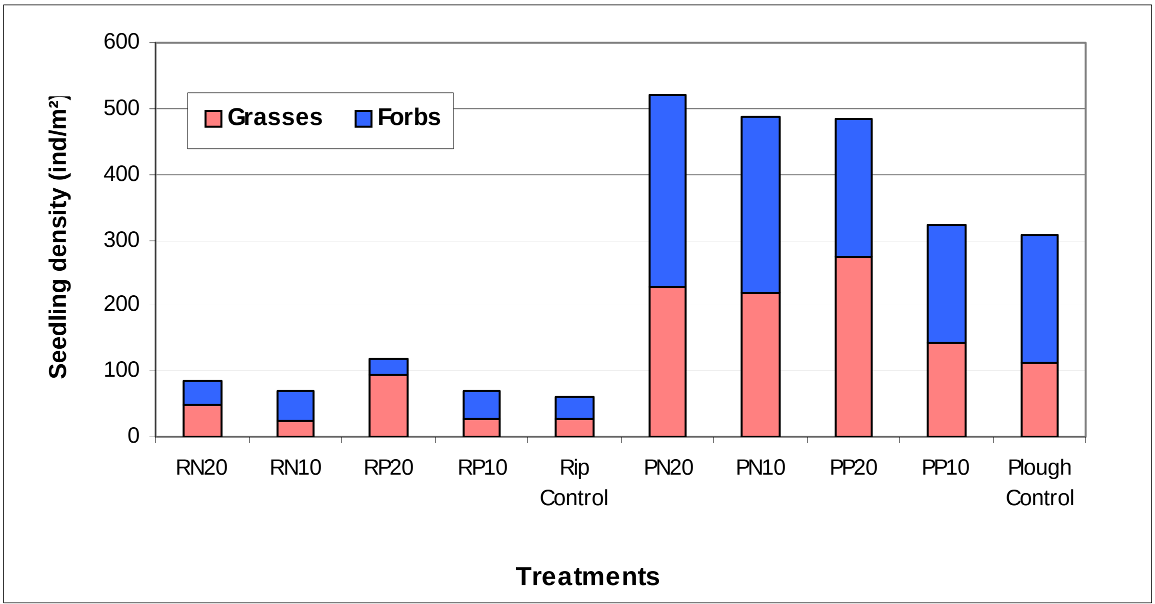


Figure 4.1: Seedling emergence (ind/m²) of grasses and forbs after establishment in all the treatments (see Table 3.1 or 4.2 for abbreviations of treatments).

Seedling emergence in the ploughed plots was on average five times higher (425 ind/m²) than in the ripped plots (81 ind/m²) (Figure 4.1). This substantial difference is most likely caused by the improved site preparation and sowing method (broadcast) that was used during establishment of the ploughed treatments. The control plots contained on average fewer seedlings than the sown plots, both in the ripped (62 ind/m² vs. 86 ind/m²) and ploughed (308 ind/m² vs. 455 ind/m²) treatments. On average for all treatments there were 253 seedlings per square meter, consisting of about equal amounts of grass and forb seedlings.

The lowest seedling emergence was sampled in the rip control plot (62 ind/m²), where the least soil disturbance was performed and no seed was introduced. Of the seeded treatments, the lowest seedling emergence was sampled in the low seeding density (10 kg/ha) plots in the rip section.

As to be expected, forbs were exclusively relic annual cropland weeds (e.g. *Tagetes minuta* and *Conyza albida* (see Table 4.4 for common names)) while the grass seedlings included weedy grass species (e.g. *Urochloa panicoides* and *Chloris virgata*) as well as sown grass species (e.g. *Eragrostis chloromelas* and *Digitaria eriantha*) as part of the various treatments.

4.2. Plant density

4.2.1. Summary of Analysis of Variance (ANOVA)

Species density data sets for the two recorded seasons (2004/05 and 2005/06) (seedling density data excluded) were analysed to explore differences in the variability of the means between sown, non-sown and all species. All six data sets (both seasons) (d.f. = 19) show significant differences between the mean values for the ten treatments (Table 4.1). The standard error of the means for the two sown species data sets (SEM = 9.5 & 3.9) are much lower than for the non-sown (SEM = 25.1 & 42.9) and all species (SEM = 25.8 & 41.4) data sets, indicating the low random variability in the means of the sown species.

The data set with the highest relative variation was data obtained for non-sown species (mainly weedy annuals) during the 2005/06 season. This data set had a coefficient variation of 57.9% compared to the lowest, which was 19.1% for the sown species during the same season. As with the standard error of the means, the least significant difference (5% level) shows the lowest variation among the sown species with highest among the non-sown and all species for the 2005/06 season.

Table 4.1: Summary of plant density (ind/m²) means of all treatments for both recorded seasons after Analysis of Variance (ANOVA) (also see Appendix A and Table 3.1 or 4.2 for treatment abbreviations).

Treatment	Sample size	Species density (2004/05 season)			Species density (2005/06 season)		
		Sown	Non-sown	All	Sown	Non-sown	All
PC	16	12.4 de	280.6 a	293.0	4.3 f	152.6 a	156.9 a
PP10	16	87.9 a	53.6 de	141.4 ab	39.9 bc	7.1 b	47 a
PP20	16	85.4 a	18.1 e	103.5 b	55.4 cde	4.9 b	60.3 a
PN10	16	65.6 ab	80.2 de	145.8 ab	35.2 bcd	30.2 ab	65.4 a
PN20	16	75.2 a	50.5 e	125.7 ab	46.6 ab	28.9 ab	75.5 a
RC	16	0.1 e	207.7 ab	207.8 a	1.1 f	351.1	352.2
RP10	16	34.1 cd	93.8 cde	127.9 ab	27.4 de	136.2 ab	163.6 a
RP20	16	43.6 bc	90.1 cde	133.6 ab	30.5cde	120.1 ab	150.6 a
RN10	16	29.7 cde	164.1 bc	193.8 a	20.9 e	76.1 ab	97 a
RN20	16	33.4 cd	133.6 bcd	167 ab	25.4 de	140.8 ab	166.2 a
Grand mean		46.7	117.2	164	28.7	104.8	133.5
SEM		9.5	25.1	25.8	3.9	42.9	41.4
F probability		0.001	0.001	0.016	0.001	0.007	0.015
LSD (5%)		30.3	80.25	82.6	12.4	137.3	132.5
CV%		28.6	30.3	22.3	19.1	57.9	43.9

Legend:
SEM is the standard error of the means.
LSD is the Fisher's protected t-test least significant difference at the 5% level.
Means per column followed by the same letter (a, b, c, d, e and f) did not differ significantly at the 5% level.
CV is the coefficient of variation in %.

4.2.2. General plant density comparisons

The twenty plots had an overall average of 164 ind/m² for the first season ($P < 0.016$, d.f = 18, CV = 23.3%) and 134 ind/m² for the second season ($P < 0.015$, d.f = 18, CV = 43.9%) (Table 4.2, Figure 4.2). Substantial differences occurred in plant density amongst the ripped plots, ploughed plots and their control plots. The treated ploughed plots produced on average 95.5 ind/m² while the control plots in the ploughed section produced a more than double density of 223 ind/m². Similarly, the ripped plots produced on average 150 ind/m² with a contrasting 280 ind/m² in the ripped control plots. These significant differences in plant density can mainly be ascribed to the presence of one species, *Tagetes minuta,* which has grown in dense upright groves in the non-seeded parts (Table 4.2, Figure 4.2).

Table 4.2: Treatment codes and their respective combined treatments (establishing method, seed mixture and seeding rate) followed by plant densities (ind/m²) for each treatment during both recorded seasons. The difference in plant density between the two seasons is also indicated.

Code	Method	Seed mixture	Seeding Rate	Season 2004/05	Season 2005/06	Difference
PP10	Plough	Pasture Grass	10 kg/ha	141	47	-94
PP20	Plough	Pasture Grass	20 kg/ha	104	60	-43
PN10	Plough	Natural Grass	10 kg/ha	145	65	-80
PN20	Plough	Natural Grass	20 kg/ha	126	76	-50
PCON	Plough	Control	0 kg/ha	293	153	-140
RP10	Rip	Pasture Grass	10 kg/ha	128	164	36
RP20	Rip	Pasture Grass	20 kg/ha	134	151	17
RN10	Rip	Natural Grass	10 kg/ha	194	97	-97
RN20	Rip	Natural Grass	20 kg/ha	168	166	-1
RCON	Rip	Control	0 kg/ha	208	352	145
Average				**164**	**134**	**-31**

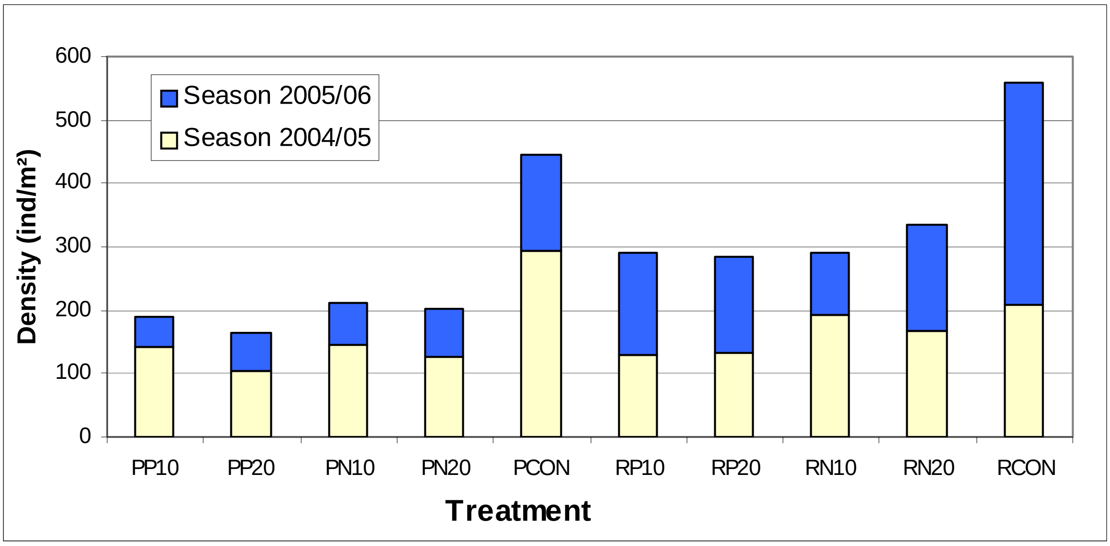


Figure 4.2: Plant density (ind/m²) for all treatments during both recorded seasons.

On the other hand, only minor plant density differences occurred between the two seed mixtures and between the two seeding rates as variables. The natural grass mixture plots produced, for both seasons, an average of 129.5 ind/m², while the pasture seed mixture produced a not so different 116 ind/m². In comparing the two seeding rates (10 and 20 kg/ha) there was also no difference in plant density as both seeding rates produced on average 122.8 ind/m² during both seasons combined. There was a slight drop in total average plant density from the first to the second season (164 to 133 ind/m²).

The following section contains a more detailed narrative of plant density data for the three restoration methods that was collectively used in this study, namely establishing methods, seed mixtures and seeding rates.

4.2.3. Plant densities between the two establishing methods

In a seven-year study in the tall grass prairies on the sandy plains of Minnesota, USA, comparisons with un-restored sites showed that site preparation plus prairie seed addition had reduced weed biomass by 94%. Prairie seed addition alone, without site preparation, had no significant effect on weed biomass (Blumenthal *et al.* 2003). Site preparation, therefore, although costly, significantly increases the success of a restoration program by reducing weed biomass.

The plough and broadcast method, which included a seedbed (site) preparation action (see section 2.3.2. on site preparation methods), produced by far the best results in terms of establishing plant species (density = 425 ind/m²). However, the most significant decrease in plant density, from a high 425 ind/m² to a low 60 ind/m², occurred in the seeded ploughed plots three seasons after establishment (Figure 4.3). This substantial difference in density was most likely caused by the initial high seedling concentration and subsequent high competition levels among individual plants (mainly perennial plants) for resources like moisture and light. Although less acute, plant density levels also decreased over time in the plough control plots (308 ind/m^2 – 157 ind/m^2).

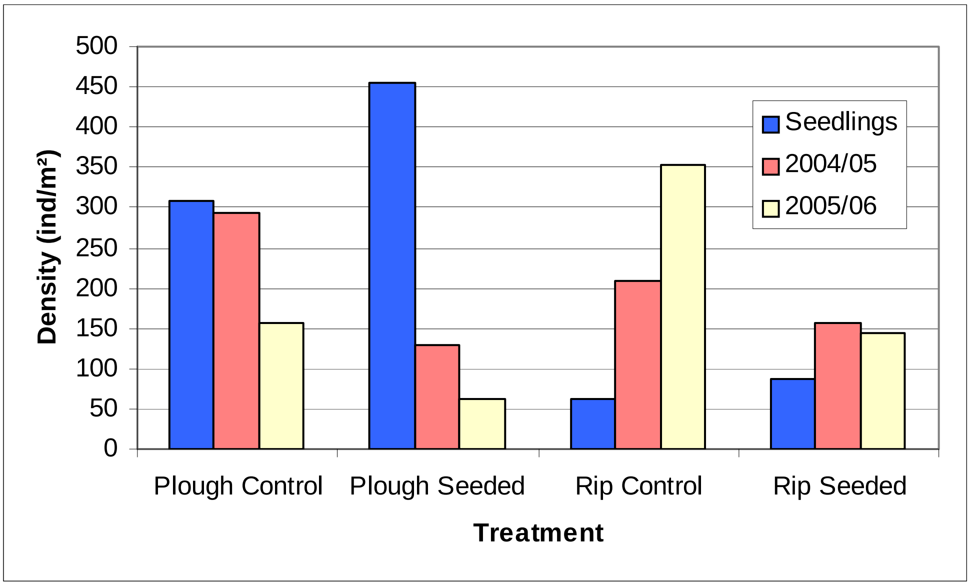


Figure 4.3: Plant densities (ind/m²) for the plough and rip methods (seeded and control plots separate) during trial establishment and the two recorded seasons (2004/05 and 2005/06).

The rip method of establishment produced much lower plant densities than the plough method during trial establishment (density = 86 ind/m^2). However, the most substantial increase in plant density over the three-season period was experienced in the rip control plots where the plant density (exclusively annual cropland weeds) increased from an initial low 62 ind/m^2 to a high 352 ind/m^2. This initial low density is probably caused by weed control during the previous seasons' crop production whilst the subsequent increase in density was caused by a flush in seed production. Plant density in the seeded rip plots also increased slightly from 86 ind/m^2 to 144 ind/m^2.

The seasonal increase or decrease of plant density among the different treatments will most likely be more stable in the future, particularly in the seeded plough treatments with its high perennial (late-successional) grass component and consequential lack of available resources to new entrants.

Although the plough method produced substantially higher seedling densities during establishment of the trials, the ripped plots had higher plant densities towards the end of the study (in both the seeded and control plots), probably due to more available moisture and light for new entrant plants between the ripped lines.

The plough method of establishment, from a visual perspective, produced a more even soil surface and a much more uniform species distribution and vegetation structure (Figures 4.4, 4.11 and 4.12). The rip method, on the other hand, produced an uneven soil surface and distinguished vegetation lines, consisting of the sown species. Due to the mainly late successional species composition of these lines, they might take a long time to disappear.

(a) (b)

Figure 4.4: The plough (a) method of establishment produced a more evenly distribution of plants while the rip (b) method established plants in parallel lines.

An important factor to keep in mind, when comparing these plant densities, is the composition of sown species (mainly perennial grasses) and non-sown species (mainly annual weeds). The non-sown species, like *Tagetes minuta*, occurs in much denser groves than the tufted perennial sown grasses, which explains the high plant densities in the control and ripped plots, where generally less perennial grasses occur, especially during the first season.

4.2.4. Weed control

An important aspect of cropland restoration is the ability of the newly established plant communities to control and resist invasive weedy species (Blumenthal *et al.* 2003). To investigate the effect of these trials on weedy plants all species were grouped into two guilds, namely sown and non-sown species. The non-sown species consisted predominantly of relict annual cropland weeds, even by the end of the study period.

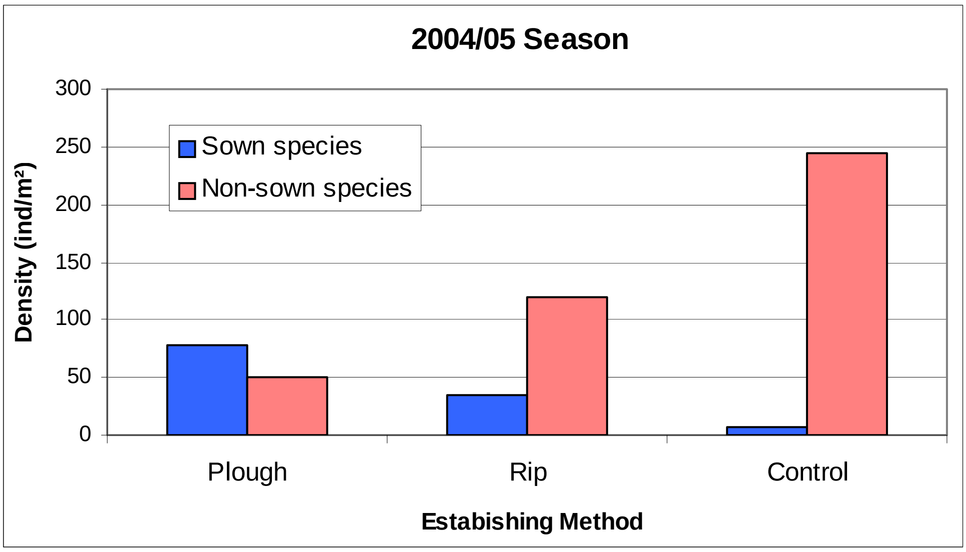
4.2.4.1. Sown species

In all plots the combined the mean plant densities for sown species ($P < 0.001$) was 47 ind/m² for the first season with the highest densities in the plough, pasture grass, 10 kg seed/ha (PP10) plots (88 ind/m²) and the lowest in the rip, natural grass, 10 kg seed/ha (RN10) plots (30 ind/m²). The sown species were obviously mainly confined to the treated plots. However, since most of the sown grasses are indigenous to the area, some low occurrences of sown species turned up in the control plots. The most notable of these species is *Cynodon dactylon* (Couch Grass), a common pioneer and grazing grass in the region.

During the second season the mean densities for sown species ($P < 0.001$) was significant lower at 29 ind/m² with the highest (55 ind/m²) recorded in the plough, pasture grass, 20 kg seed/ha (PP20) plots and the lowest (21 ind/m²) recorded in the rip, natural grass, 10 kg seed/ha (RN10) plots. The sown species dominated from the start in the ploughed plots (Figure 4.5), where conditions for germination and establishment were optimal.

4.2.4.2. Non-sown species

Conversely, the non-sown species, being represented within the local soil seed bank, were present at various densities in all plots, but highest in the control plots. In general, higher densities of non-sown species were recorded than with sown species during both seasons (Table 4.1, Figure 4.5). The mean density of non-sown species in all ten treatments during the first season ($P< 0.001$) was 117 ind/m² and during the second season ($P<0.007$) not much lower at 105 ind/m².



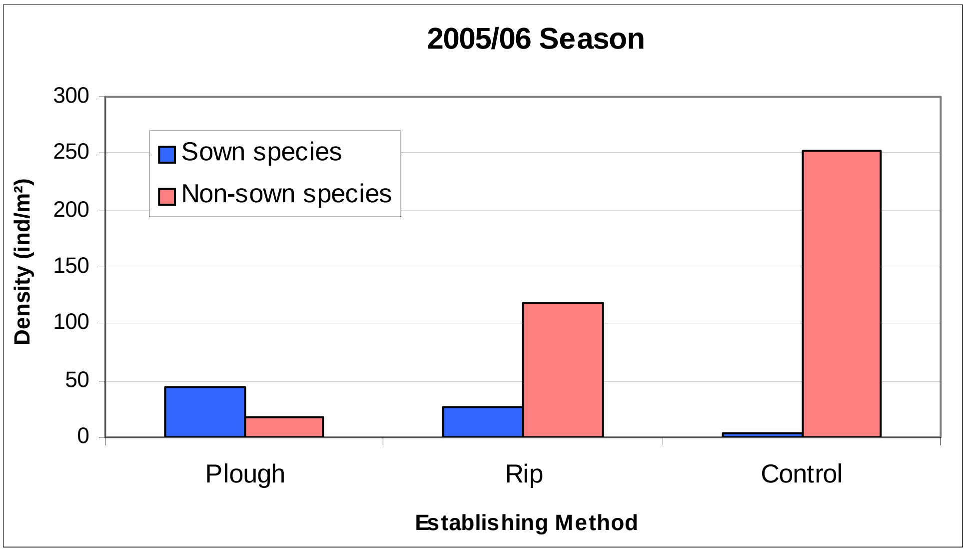


Figure 4.5: Plant densities of sown and non-sown species for plough, rip and control treatments during the two recorded seasons.

During the first season the highest non-sown plant density was recorded in the plough control (PCON) plots at 281 ind/m² and the lowest in the plough, pasture grass, 20 kg seed/ha (PP20) plots at only 18 non-sown ind/m², showing considerable variation among the treatment means (CV = 30.3%). During the second season the highest non-sown plant density was recorded in the rip control (RCON) plots at a staggering 351 ind/m² and the lowest in the plough, pasture grass, 20 kg seed/ha (PP20) plots at a very low 5 non-sown ind/m², showing again considerable variation among the treatment means (CV = 57.9%) (Table 4.1).

The high non-sown plant densities in the control plots can mainly be attributed to two species, *Tagetes minuta* and *Urochloa panicoides,* which grew in dense groves (Figure 4.17) and are both commonly cultivated cropland weeds in the area. It is interesting to note that the densities of non-sown species in the plough control plots decreased during the second season but increased during the same season in the rip control plots. The decrease of non-sown species densities in the plough control plots were likely caused by an initial high germination rate, due to improved site preparation. Subsequently the lower seed densities, lack soil disturbance and lower levels of nutrients (particularly N) towards the last season caused a decrease in germination and/or survival rate of the mainly annual non-sown species in the plough treatments. The initial low non-sown species densities in the r ip control plots were likely caused by the lack of soil disturbance (and release of nutrients) during establishment. The increase of non-sown species densities over time is difficult to explain, but has probably something to do with the availability and release of nutrients and the viable seed bank which were still present.

Perhaps the most significant, for successful restoration, is that the plough plots were dominated by sown-species and the rip plots dominated by non-sown species (Figure 4.5) throughout the study period. The plough plots were also able to reduce the densities of non-sown species in time where the densities of non-sown species remained much the same in the ripped treatments. During the second season, however, the plants of non-sown species were small and generally out-competed by the perennial grasses, even in the rip plots (Figures 4.9 – 4.12).

4.2.5. Plant densities between the two seeding rates

There were no significant differences in sown species and non-sown species plant densities between the two seeding rates used (10 and 20 kg seed/ha) in this study during both recorded seasons (Figure 4.6). The average densities of sown species for the two seeding rates during the study period were remarkably similar at 49 ind/m^2 (20 kg/ha) and 43 ind/m^2 (10 kg/ha) respectively. Similarly, plant densities for non-sown species averaged at 80 ind/m^2 (10 kg/ha) and 73 ind/m^2 (20 kg/ha) respectively. If the densities for these two plant groups are combined, the two seeding rates produced exactly the same plant density (123 ind/m^2).

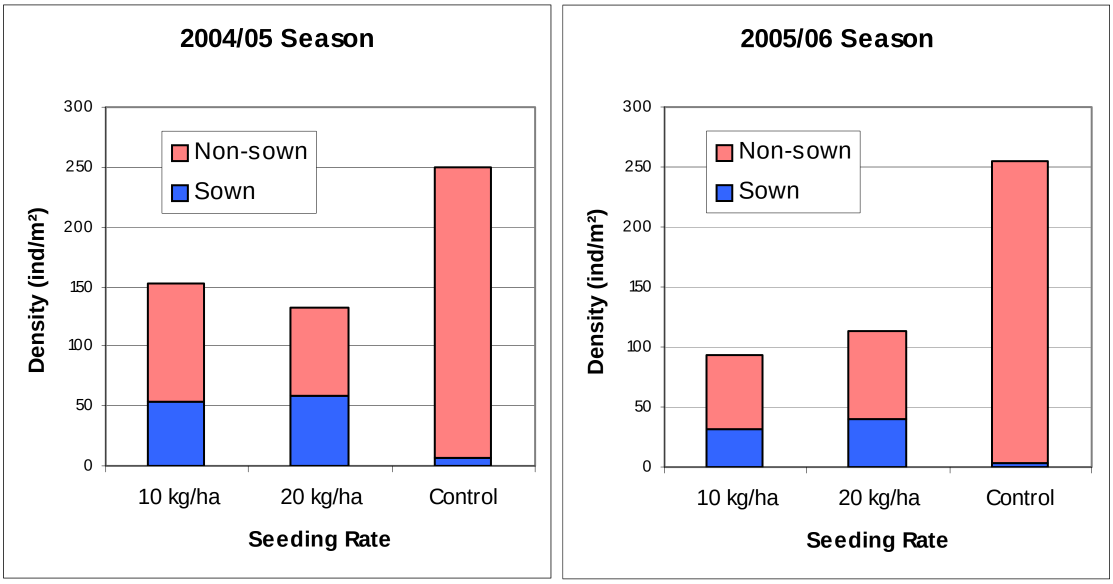


Figure 4.6: Plant densities of sown and non-sown species for the two seeding rates and control treatments.

The highest plant density, however, was sampled in the control plots with an average density of 252 ind/m^2 (Figure 4.6) for both seasons combined. The plant densities (sown and non-sown species) for both seeding rates decreased towards the end of the trial, indicating that generally high seeding rates were used in combination with exceptionally good climatic conditions during establishment.

4.2.6. Plant densities between the two seed mixtures

Throughout the study period plant densities for sown species were much the same between the two seed mixtures (natural grasses and pasture grasses) (Figure 4.7). The difference in densities for the non-sown species (mainly cropland weeds) were however more significant ($P = 0.001$ & $P = 0.007$). During seedling emergence and the first season (2004/05), higher densities of non-sown species were sampled in the natural grass plots (107 ind/m^2) than in the pasture grass plots (64 ind/m^2). This is difficult to explain but might be due to more early successional species, which are less competitive, in the natural grass seed mixture than the predominantly strong late successional species contained by the pasture seed mixture.

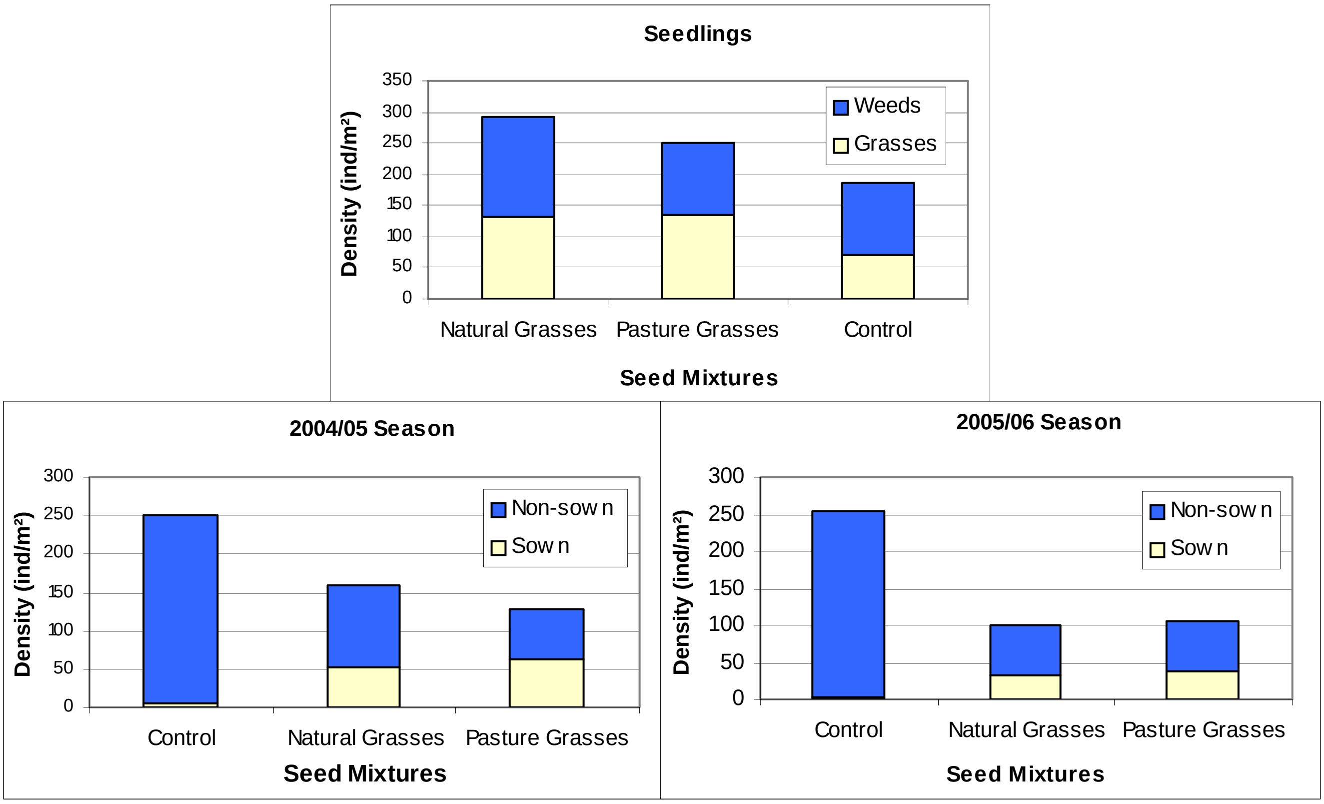


Figure 4.7: Plant densities for the two seed mixtures during seedling emergence and the two recorded seasons.

However, towards the end of the study little differences occurred in sown and non-sown plant densities between the two seed mixtures. Although higher densities of non-sown species occurred in the seeded treatments, these non-sown cropland weeds were generally weak and in a vegetative stage, even though it was towards the end of the growing season. This lack of prominence can better be seen in the photographs (Figures 4.9 – 2.16 (b)). As to be expected, the control plots were dominated by non-sown species throughout the trial period. In both seed mixtures the plant densities decreased with time, particularly the density of sown species (also see Figures 4.17 and 4.18).

Of the three collectively used restoration methods, namely establishing method, seed mixtures and seeding rates, as described above, the establishing methods (plough and rip) clearly had the most significant influence on plant density and establishment of the sown species.

However, of equal importance is the increase and decrease of early- and late successional species, as this indicates the trajectory movement of the various treatments in terms of secondary succession. Below follows a plant density description where the species sampled are grouped into three plant guilds, namely annual (all non-sown by connotation), non-sown perennial and sown (all perennial by connotation) plants.

4.2.7. Plant densities of annual and perennial plants

Although perennial plants were mainly introduced and annual plants were present in the local seed bank during the start of the project, there were slight changes in their respective densities during the trial period.

Table 4.3: Plant densities (ind/m^2) for non-sown annual and perennial species as well as sown species among the various treatments during the two recorded seasons (2004/05 and 2005/06).

	Season 2004/05				Season 2005/06			
Treatment	Annual Non-sown	Perennial Non- sown	Sown Species	Total	Annual Non-sown	Perennial Non- sown	Sown Species	Total
RP10	92	1	34	127	125	12	27	164
RP20	88	2	44	134	115	5	31	151
RCON	200	7	0	207	293	57	2	352
RN10	149	0	45	194	48	16	32	96
RN20	115	9	44	168	122	6	38	166
Rip Average	**129**	**4**	**33**	**166**	**141**	**19**	**26**	**191**
PP10	53	1	88	142	7	0	40	47
PP20	17	1	85	103	4	0	55	59
PCON	289	1	3	293	148	5	1	154
PN10	33	4	108	145	3	2	61	66
PN20	20	6	99	125	2	2	71	75
Plough Average	**82**	**3**	**77**	**162**	**33**	**2**	**46**	**80**
Total	1056	32	550	1638	867	105	358	1330
Average	106	3	55	164	87	11	36	134

The average number of strictly annual plants dropped from 106 to 87 ind/m^2 while there was an increase in the number of non-sown perennials (mainly weak perennials), from 3 to 11 ind/m^2, as time progressed (Table 4.3 and Figure 4.8). This increase in new entrant perennial plants indicates some secondary succession, although limited.

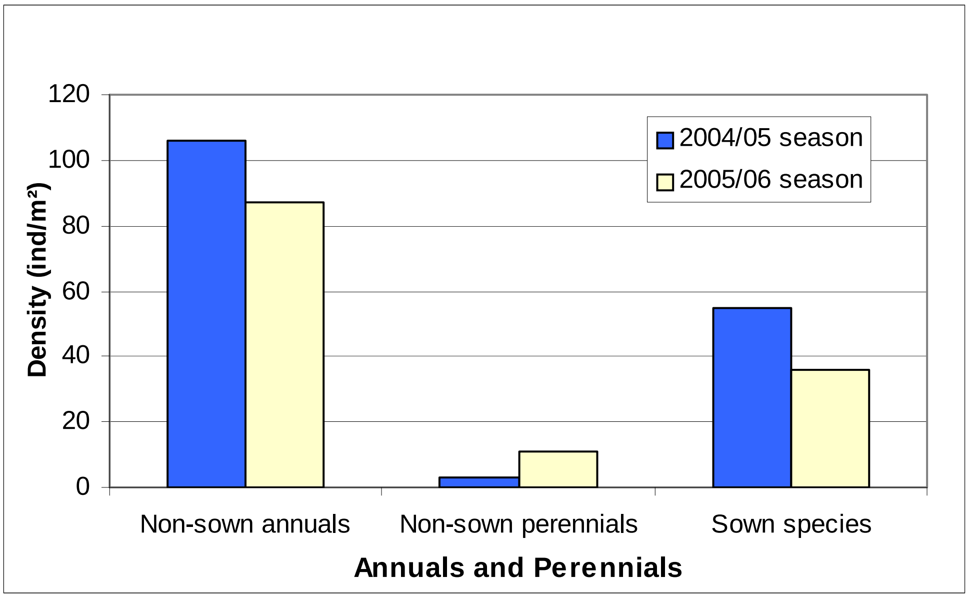


Figure 4.8: Plant densities for annual and perennial species during both recording seasons.

The increase in non-sown perennial plants (e.g. *Pseudognaphalium undulatum, Nemesia fruticans*) was much more profound in the rip plots (from 4 to 19 ind/m^2) than the plough plots (from 3 to 2 ind/m^2) (Table 4.3). This increase can most probably be ascribed to the fact that the ripped plots had open spaces between the rip lines with consequently higher levels of available resources, like moisture, light and nutrients, for new entrant plants, than the more dense plough plots.

On the other hand, and somewhat contradictory, the strong perennial plants, which were exclusively introduced through seeding, decreased on average in density, from 55 to 36 ind/m^2 (Table 4.3). This decline in plant density was most probably caused by high levels of interplant competition, which was brought about by high seeding rates used (10 and 20 kg seed/ha) and optimum conditions for germination experienced during establishment. The presence of non-sown perennial plants increased on average from 3 to 11 ind/m^2 (Table 4.3).

4.3. Plant species

Plant species density (ind/m^2) data were collected in order to identify dominant species during the trials, to monitor the increase and decrease of species density and to compare the species composition with that of natural rangeland. Below is a description of species density recorded during the study.

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4.3.1. Species recorded during the trials

A total number of 36 plant species (Table 4.4) were recorded during sampling of plant density data during the first ($P < 0.016$) and second ($P < 0.015$) season (control plots included). Plants recorded were mainly the sown species and annual cropland weeds. However, a third group of plants, the non-introduced perennials appeared in low numbers towards the end of the trial period. These plants are mainly weak perennial, except for *Hyparrhenia hirta* (see Table 4.4 for common names), which is a strong perennial grass (Gibbs Russel *et al.* 1990, van Oudtshoorn 1999).

The two most common plants recorded during both seasons were the broadleaf weed *Tagetes minuta* and the grass weed *Urochloa panicoides* (Table 4.4). Both species are common annual weeds in the Highveld region of South Africa (Bromilow 1996, Grabandt 1985). These species were particularly common in the control and rip plots, where reduced vegetation densities caused higher levels of available resources; which were more favourable for annuals, than the densely populated ploughed plots. The four most common sown species were *Eragrostis chloromelas*, *E. curvula, E. plana* and *Digitaria eriantha*. The two least common sown-in species were *Panicum maximum* and *Cynodon dactylon* (Table 4.4).

The average number of plants dropped slightly, from 164 to 133 ind/m², between the seasons of 2004/05 and 2005/06. This is particularly the case with some sown species, such as *Eragrostis chloromelas*, *E. curvula* and *E. plana,* where plant density was extremely high and inter-plant competition intense. Although the former two species slightly decreased in number after the first season, they were still the two most common perennial species by the end of the trial period. Another sown species, which significantly decreased over time due to high competition levels, was the rather small grass *Cynodon dactylon*.

Table 4.4: Density (ind/m²) of species recorded during both seasons as well as change in density between the two seasons. Species are arranged from top to bottom according to their abundance. Sown species are indicated with a "s" behind the species name. A minus (-) symbol in the far right column indicates a decrease in species density.

Species	**Abbreviation**	**Common Name**	**Season 2004/05**	**Season 2005/06**	**Average**	**Seasonal change**
Tagetes minuta	*Tag min*	Khakiweed	54.37	54.64	54.51	0.27
Urochloa panicoides	*Uro pan*	Garden urochloa	31.79	21.19	26.49	-10.60
Eragrostis chloromelas (s)	*Era chlS*	Curly leaf love grass	16.52	10.84	13.68	-5.68
Eragrostis curvula (s)	*Era curS*	Weeping love grass	16.84	8.61	12.73	-8.23
Eragrostis plana (s)	*Era plaS*	Tough love grass	10.26	8.08	9.17	-2.18
Digitaria eriantha (s)	*Dig eriS*	Smuts finger grass	6.18	6.08	6.13	-0.10
Schkuhria pinnata	*Sch pin*	Dwarf marigold	8.98	1.51	5.24	-7.46
Chloris virgata	*Chl vir*	Feathertop chloris	2.15	5.93	4.04	3.78
Cyperus esculentus	*Cyp esc*	Yellow nutsegde	2.99	2.67	2.83	-0.32
Conyza albida	*Con alb*	Tall fleabane	2.96	0.99	1.97	-1.97
Cenchrus ciliaris (s)	*Cen cilS*	Blue buffalo grass	2.42	1.04	1.73	-1.38
Senecio consanguineus	*Sen con*	Starvation senecio	1.60	1.68	1.64	0.08
Pseudognaphalium undulatum	*Pse und*	Cudweed	0.89	2.29	1.59	1.39
Nemesia fruticans	*Nem fru*	Wild nemesia	0.00	3.15	1.58	3.15
Heteropogon contortus (s)	*Het conS*	Spear grass	0.96	0.84	0.90	-0.12
Melinis repens (s)	*Mel repS*	Natal red-top	0.89	0.66	0.77	-0.23
Cynodon dactylon (s)	*Cyn dacS*	Couch grass	1.22	0.09	0.65	-1.13
Panicum schinzii	*Pan sch*	Sweet buffalo grass	1.11	0.10	0.60	-1.01
Eleusine coracana subsp. *africana*	*Ele cor*	Goose grass	0.06	0.59	0.33	0.53
Panicum maximum (s)	*Pan maxS*	Buffalo grass	0.59	0.05	0.32	-0.54
Walenbergia caledonica	*Wal cal*	Blue bell	0.00	0.59	0.29	0.59
Amaranthus hybridus	*Ama hyb*	Common pigweed	0.16	0.36	0.26	0.21
Ciclospermum leptophyllum	*Cic lep*	Wild celery	0.36	0.07	0.21	-0.29
Bidens bipinnata	*Bid bip*	Spanish blackjack	0.13	0.24	0.19	0.11
Oxalis latifolia	*Oxa lat*	Garden sorrel	0.09	0.21	0.15	0.11
Digitaria sanguinalis	*Dig san*	Crab finger grass	0.18	0.11	0.14	-0.07
Hyparrhenia hirta	*Hyp hir*	Common thatching grass	0.01	0.19	0.10	0.18
Xanthium strumarium	*Xan str*	Large cocklebur	0.03	0.15	0.09	0.13
Verbena brasiliensis	*Ver bra*	Purple top	0.01	0.10	0.05	0.09
Lepidium bonariense	*Lep bon*	Pepper weed	0.08	0.01	0.04	-0.07
Aristida congesta subsp. *congesta*	*Ari con*	Tassel three-awn	0.08	0.00	0.04	-0.08
Pogonarthria squarrosa	*Pog squ*	Herringbone grass	0.00	0.07	0.03	0.07
Eragrostis rigidior	*Era rig*	Curly leaf	0.06	0.00	0.03	-0.06
Plantago lanceolata	*Pla lan*	Narrow-leaved plantain	0.03	0.00	0.01	-0.03
Eragrostis cillianensis	*Era cil*	Stink love grass	0.01	0.01	0.01	0.01
Sonchus oleraceus	*Son ole*	Sowthistle	0.00	0.01	0.01	0.01
Average number of ind/m²			**163.94**	**133.12**	**148.53**	**-30.81**

Similarly, *Panicum maximum*, a tropical species, occurring locally only in sheltered habitats, decreased and almost disappeared completely by the end of the trial period. *Cenchrus ciliaris* followed the same downward trend and ended with one plant per Meter Square during the last survey.

Some of the non-sown species, such as *Schkuhria pinnata* and *Conyza albida*, decreased notably in abundance between the first and second recorded seasons. Both these species are strongly annual cropland weeds introduced from South America (Bromilow 1996, Grabandt 1985). A number of species increased during the second recorded season, of which *Pseudognaphalium undulatum, Nemesia fruticans* and *Chloris virgata* were the main ones. All three species are indigenous, weakly perennial and, except for *C. virgata*, not common cropland weeds in South Africa (Germishuizen & Meyer 2003, Bromilow 1996, Van Wyk & Malan 1988).

Another plant that increased towards the end of the trial period was *Hyparrhenia hirta* (Common Thatching Grass). *H. hirta* commonly occurs within the study area and, as discussed in chapter two (Study Area), commonly invades previously cultivated cropland. This grass, due to its competitive nature, often dominates the species composition with a subsequent decrease in diversity. *H. hirta* was occurring (in low densities) first in the control plots but also eventually in the ripped plots (Figures 4.22 and 4.23). By the end of the trial period there were as yet no occurrences of *H. hirta* in the plough treatments.

4.3.2. Species composition resemblance to natural rangeland

In the adjacent natural rangeland the cover was mainly dominated by natural C_4 grasses with a fair number of forb species (Table 4.5). No annual plants were among the 17 most common plants in the natural rangeland surrounding the study area (Hoare 2006). In the treated area (control treatments excluded) the most common plants in the species composition during the second season were also C_4 perennial grasses (all sown) but with an almost equal number of annual weeds. Only one local forb species was recorded among the 17 most common plants during the second growth season.

Table 4.5: List of common species and their growth forms recorded in natural rangeland and treated plots arranged according to abundance.

Natural Rangeland		**Treated Plots (control excluded)**	
Species	**Growth form**	**Species**	**Growth from**
Setaria sphacelata	Perennial C_4 Grass	*Tagetes minuta*	Annual broadleaf weed
Themeda triandra	Perennial C_4 Grass	*Urochloa panicoides*	Annual grass weed
Elionurus muticus	Perennial C_4 Grass	*Eragrostis chloromelas (s)*	Perennial C_4 Grass
Brachiaria serrata	Perennial C_4 Grass	*Eragrostis curvula (s)*	Perennial C_4 Grass
Acalypha caperonioides	Forb	*Eragrostis plana (s)*	Perennial C_4 Grass
Helichrysum rugulosum	Forb	*Digitaria eriantha (s)*	Perennial C_4 Grass
Trachypogon spicatus	Perennial C_4 Grass	*Cenchrus ciliaris (s)*	Perennial C_4 Grass
Diheteropogon amplectens	Perennial C_4 Grass	*Chloris virgata*	Annual grass weed
Eragrostis chloromelas	Perennial C_4 Grass	*Cyperus esculentus*	Sedge weed
Eragrostis curvula	Perennial C_4 Grass	*Conyza albida*	Annual broadleaf weed
Eragrostis racemosa	Perennial C_4 Grass	*Heteropogon contortus (s)*	Perennial C_4 Grass
Bewsia biflora	Perennial C_4 Grass	*Melinis repens (s)*	Perennial C_4 Grass
Cymbopogon excavatus	Perennial C_4 Grass	*Cynodon dactylon (s)*	Perennial C_4 Grass
Hypoxis iridifolia	Forb	*Senecio consanguineus*	Forb
Pentanisia angustifolia	Forb	*Pseudognaphalium undulatum*	Annual broadleaf weed
Senecio species	Forb	*Panicum maximum (s)*	Perennial C_4 Grass
Ziziphus zeyheriana	Dwarf shrub	*Digitaria sanguinalis*	Annual grass weed

4.3.3. Visual resemblance to natural grassland

Due to the establishing method the ripped plots have clear lines where the seed was sown and plants subsequently established. This is more evident in the sown pasture plots (Figures 4.11 and 4.12) where high quality certified seed ensured high rates of germination. As mentioned before, these lines are also evident at soil surface level where the lines are slightly elevated. In comparison, the ploughed plots facilitated a more evenly distribution of soil and seed which resulted in a more level soil surface and improved plant spatial distribution.

The natural grass mixture, in all its treatments, during the second season, visually resembled natural grassland more, in terms of structure and spatial distribution of species, than the pasture grass mixture, which has an even distribution of mainly one dominating species (*Eragrostis curvula*) (Compare Figures 4.9 – 4.16).

The control plots (Figures 4.17 and 4.18) show visually little difference between the two seasons and between each other and show no visual resemblance to natural grassland in comparison to the seeded plots. The control plots in both the ripped and ploughed sections contained a visual presence of the *Hyparrhenia hirta*, which has a reputation of invading and dominating disturbed areas for extended periods (Bredenkamp & Brown 2003).

Figure 4.9: Ripped/native grasses/10 kg/ha (RN10) plots for 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 128 and 164 ind/m² respectively.

Figure 4.10: Ripped/native grasses/20 kg/ha (RN20) plots for 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 167 and 166 ind/m² respectively.

Figure 4.11: Ripped/pastures grasses/10 kg/ha (RP10) for 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 128 and 164 ind/m² respectively.

Figure 4.12: Ripped/pasture grasses/20 kg/ha (RP20) plots for 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 134 and 151 ind/m² respectively.

Figure 4.13: Plough/native grasses/10 kg/ha (PN10) plots for both 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 146 and 65 ind/m² respectively.

Figure 4.14: Plough/natural grasses/20 kg/ha (PN20) plots for both 2004/05 (a) 2005/06 (b). Plant densities are 126 and 76 ind/m² respectively.

Figure 4.15: Plough/pasture grasses/10 kg/ha (PP10) plots for both 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 142 and 47 ind/m² respectively. Open patch in middle is due to phytomass collection.

Figure 4.16: Plough/pasture grass/20 kg/ha (PP20) plots for 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 105 and 60 ind/m² respectively.

Figure 4.17: Ripped control plots for both 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 208 and 352 ind/m² respectively. Note the presence of *Hyparrhenia hirta* in the back of the 2005/06 plot.

Figure 4.18: Control plots for plough section during both 2004/05 (a) and 2005/06 (b) seasons. Plant densities are 293 and 157 ind/m² respectively. Note the presence of *Hyparrhenia hirta* (Front left) in the 2005/06 plot.

The above set of photographs gives a visual description of the vegetation in terms of resemblance to natural grassland and development during the study period. For a more detailed investigation on the relationship between the various treatments and their related plant species, ordination analyses were carried out and are presented in the following section.

4.4. Ordination analysis of treatment and species density scores

Because the treatments are nominal variables, high expected species versus treatment (sample) correlations were found and many species had a high redundancy and almost unimodal distribution towards their respective treatments. This gave a clustering effect of species distribution on the ordination biplots, especially towards the second season. For the same reason, some of the treatments were either multicolinear (e.g. the rip pasture grass 20 kg seed/ha (RP20) and rip pasture grass 10 kg seed/ha (RP10)) or some almost completely orthogonal (e.g. the rip pasture grass 20 kg seed/ha (RP20) and plough natural grass 20 kg seed/ha (PN20)). This caused high similarities between the two treatments within each treatment group (rip pasture grass, rip natural grass, plough pasture grass and plough natural grass) but low similarities among the groups.

In all the ordination analyses carried out the ripped treatment scores were situated nearest to the centroid, illustrating their close proximity to the mean of the multivariate data set. The non-sown species had the highest inertia, especially during the first season. As a whole, seeding density (10 kg or 20 kg seed/ha), as part of the categorical treatment, had little influence on the spatial distribution of treatment scores. Below follows interpretations of the various Principle Component Analyses (PCA) carried out.

4.4.1. Ordination of 2004/05 season data

During the first season a positive correlation (r = 0.604) was found between the various treatment scores and species scores (Figure 4.19). The highest correlation was found between the various ploughed treatments (PP and PN) and the sown species (e.g. *Cenchrus ciliaris, Eragrostis curvula, Melinis repens* and *Heteropogon contortus*), while the ripped treatments (RP and RN) were less strongly correlated with sown species but stronger correlated with non-sown species as can be seen by the proximity of species towards the treatments (Figure 4.19).

Nearest to the centroid were the four ripped treatments, indicating their general positive correlation to sown as well as non-sown species during the first season. Non-sown species (e.g. *Chloris virgata, Cyperus esculentus, Conyza albida, Senecio consanguineus, Pseudognaphalium undulatum* and *Urochloa panicoides*) were also generally located near the centroid, showing their high inertia and correlation towards all treatments. The maximum beta diversity was found between the ploughed pasture (PP20) and the ploughed natural grass (PN20) treatments, primarily due to no similarities between the two seed mixtures (pasture and natural grasses) used in this study. It is clear from the biplot that non-sown species (mainly weedy annuals) are much stronger related to the control (RCON and PCON) and rip treatments (RP10,

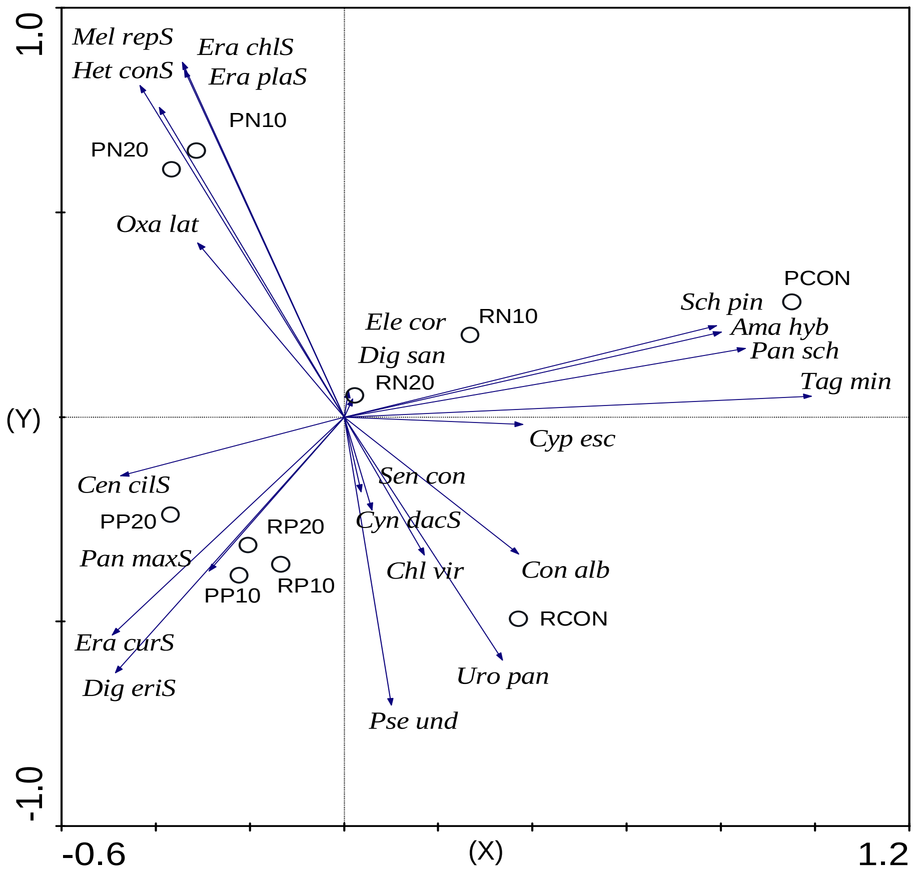

Figure 4.19: Principle Component Analysis ordination biplot showing correlations between treatment and species scores during the first recorded season (2004/05). Eigenvalues on the X- and Y- axes are 0.604 and 0.197 respectively. See Table 4.4 for species abbreviations.

RP20, RN10 and RN20) than the plough treatments (PP10, PP20, PN10 and PN20). Treatments of the same establishing method and seed mixture (e.g. PP10 and PP20), but different seeding densities, are situated on the same line and direction, showing the little influence seeding density had on the species scores.

4.4.1.1. Ordination of rip treatment scores during the first season

Positive correlations (*r* = 0.674) between treatment scores and species scores are visible (Figure 4.20) for all ripped treatments during the first season. All sown species scores show a strong correlation with their respective treatment scores. As also mentioned above, the natural sown grasses, notably *Eragrostis plana, Heteropogon contortus* and *E. chloromelas,* are strongly correlated to the RN10 and RN20 treatments with the non-sown species *Digitaria sanguinalis* also correlated to both treatments. The sown pastures grasses, notably *E. curvula* and *Digitaria eriantha*, are strongly related to the RP10 and RP20 treatments with the non-sown species

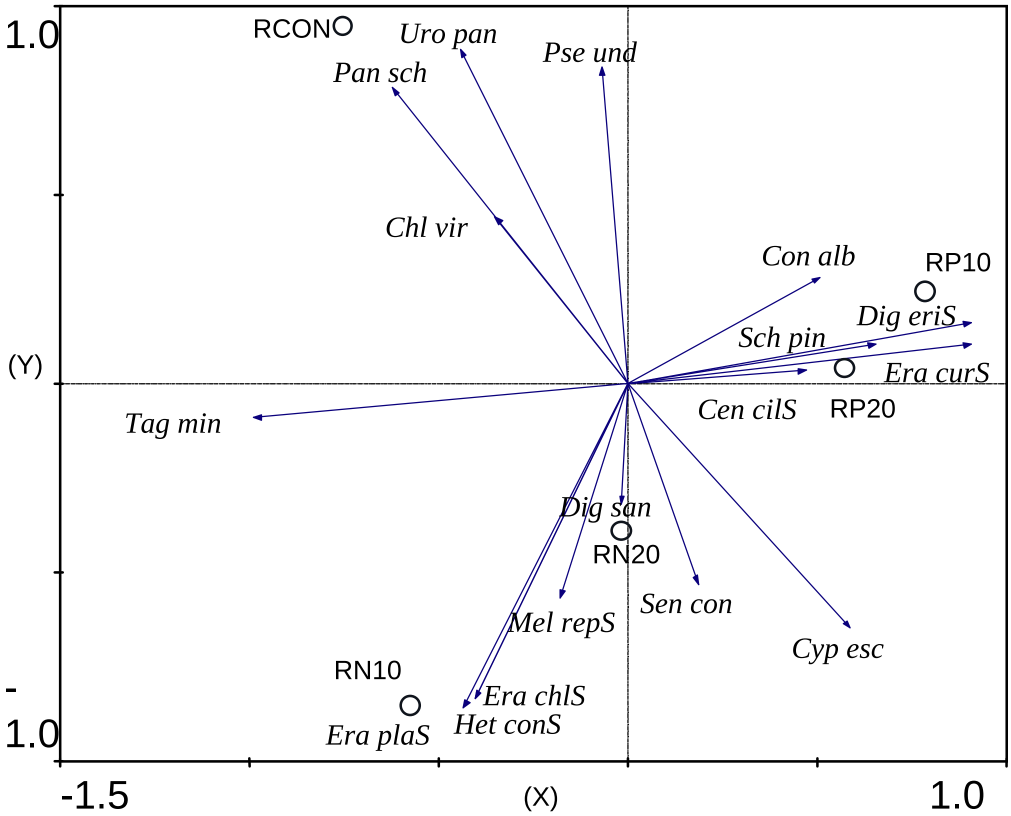

Figure 4.20: Principle Component Analysis ordination biplot showing correlations between treatment and species scores for ripped plots only during the first recorded season (2004/05). Eigenvalues on the X- and Y- axes are 0.674 and 0.277 respectively. See Table 4.4 for species abbreviations.

Schkuhria pinnata also strongly related to these treatments and with the sown species *Cenchrus ciliaris* more directly related to the RP20 treatment (Figure 4.20). The ordination plot also shows that most non-sown species scores are well distributed, except for *Panicum schinzii*, which has an exceptionally strong correlation with the control treatment score (Figure 4.20). The most common species during the first season, *Tagetes minuta,* were more strongly related to the control and Rip natural grass treatments than the Rip pasture grass treatments.

4.4.1.2. Ordination of plough treatment scores during the first season

General strong positive correlations (*r* = 0.764) are shown between treatment scores and species scores (Figure 4.21) for the ploughed treatments during the first season. As with the ripped treatments, the sown species (natural grasses such as *Melinis repens* and *Heteropogon contortus* and pasture grasses such as *Digitaria eriantha* and Eragrostis *curvula*) are correlated to their respective treatments. However, in the ploughed treatment ordination, the treatments versus species correlations are much stronger than with the ripped treatments. These strong correlations are visible on the biplot as a clustering distribution of species scores towards their respective treatment scores (Figure 4.21).

The sown grass *Cynodon dactylon,* which is also a local pioneer grass, shows some correlation with the control treatment, although closer correlated to the plough plots. The distribution of non-sown species (especially *Schkuhria pinnata* and *Panicum schinzii)* is, in comparison to the ripped treatments, also much stronger correlated to the control treatments. The species nearest to the centroid in the plot, and therefore most widely distributed among the treatments, are *Urochloa panicoides, Conyza albida* and *Cyperus esculentus*.

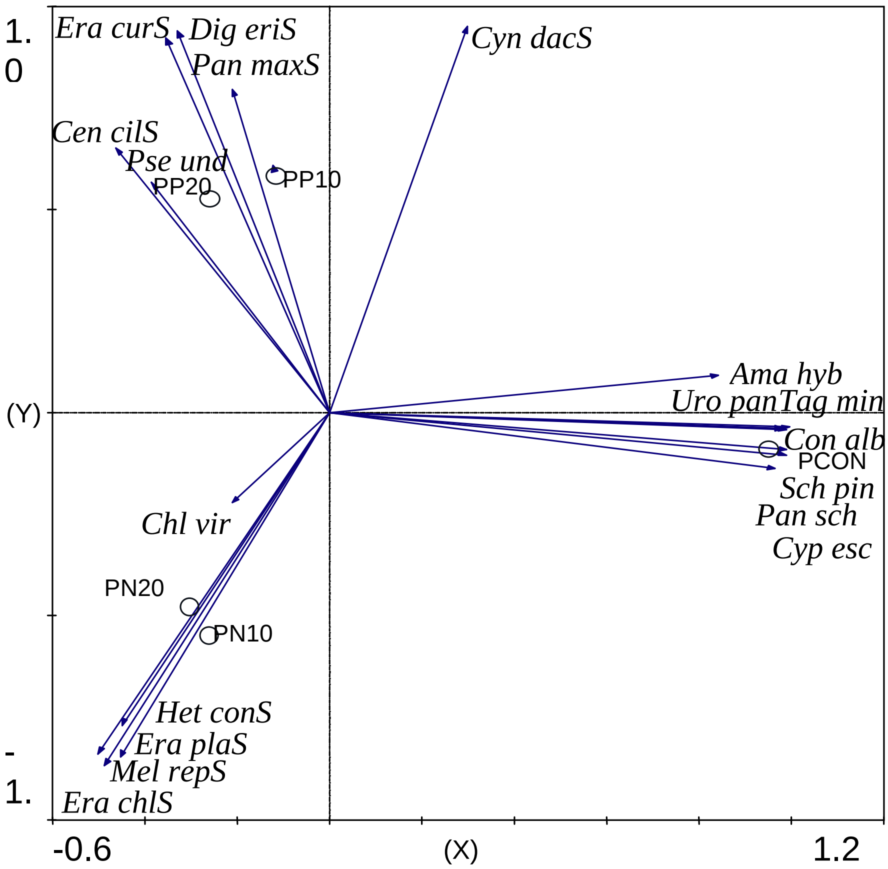

Figure 4.21: Principle Component Analysis ordination biplot showing correlations between treatment and species scores for ploughed plots during the first recorded season (2004/05). Eigenvalues on the X- and Y- axes are 0.764 and 0.223 respectively. See Table 4.4 for species abbreviations.

4.4.2. Ordination of 2005/06 season data

During the second season correspondence analyses show a somewhat stronger positive correlation (r = 0.854) between treatments and species scores (Figure 4.22) than during the first recorded season (r = 0.604). The largest beta-diversity was between the rip pasture treatments and the ploughed natural grass treatments. The sown species scores ($P < 0.001$) are generally highly correlated with their respective treatments while non-sown species scores ($P < 0.007$) are further spread along the gradient.

The two ploughed treatment groups (plough pasture (PP) and plough natural grass (PN)) are strongly negative correlated (completely separated on the first axis) and

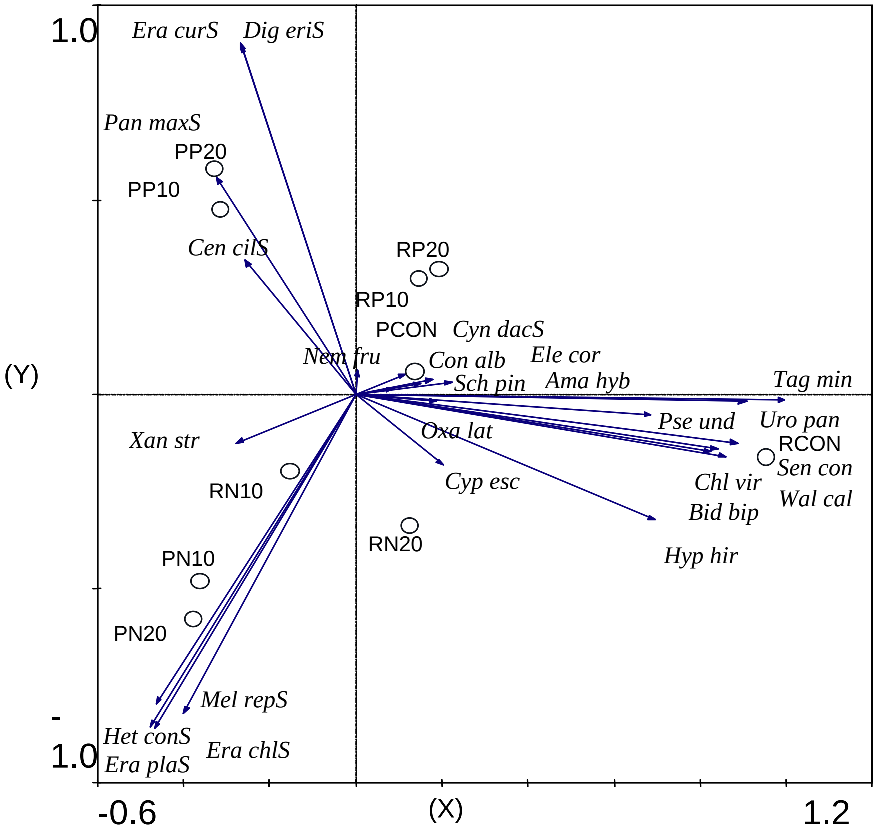

Figure 4.22: Principle Component Analysis ordination biplot showing correlations between treatment and species scores during the second recorded season (2005/06). Eigenvalues on the X- and Y-axes are 0.854 and 0.084 respectively. See Table 4.4 for species abbreviations.

both are negatively correlated to the control treatments (separated on the second axis). This distant proximity from their control treatments indicates their efficiency as treatments. The two ripped treatment groups are nearest to the centroid, indicating their close proximity to the mean score and their important share in the overall species composition in terms of non-sown species (e.g. *Nemesia fruticans* and *Conyza albida*). On the other hand, the ploughed treatments were the furthest from the centroid, indicating their distant position from the overall mean score. This also indicates that the species composition of the ripped treatments, compared to the control, is less altered than the ploughed treatments. During both seasons, seeding density (10 and 20 kg seed/ha), as a variable, exhibits a less strong influence on treatment correlations than seed mixture (pasture and natural grasses) and establishing method (rip and plough). The latter two groups form clear groups on the biplots.

4.4.2.1. Ordination of rip treatment scores

There were positive correlations (*r* = 0.303, 0.893) between the sown grasses and their respective treatments as well as the non-sown species and the control treatments (Figure 4.23) during the second season. The strongest correlation was found between the sown pasture grasses *Eragrostis curvula* and *Digitaria eriantha* and the rip/pasture grass (RP) treatments. Equally strong was the relation between the natural sown grasses *Eragrostis chloromelas, E. plana, Heteropogon contortus, Melinis repens* and the rip/natural grass (RN) treatments.

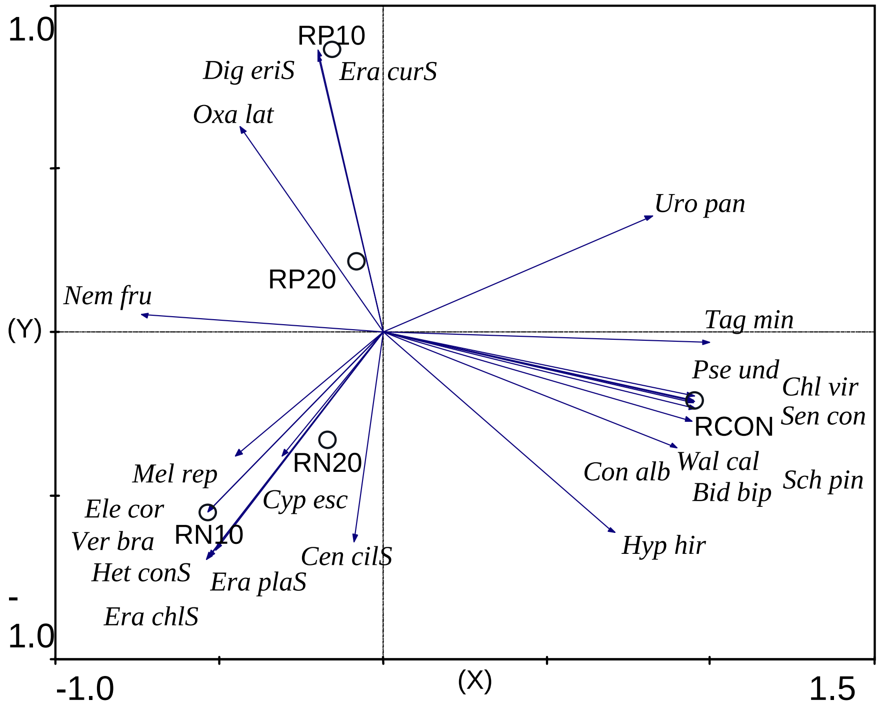

Figure 4.23: Principle Component Analysis ordination biplot showing correlations between treatment and species scores for ripped treatments during the second recorded season (2005/06). Eigenvalues on the X- and Y- axes are 0.893 and 0.055 respectively. See Table 4.4 for species abbreviations.

The control treatment had a host of non-sown (mainly annual) species located in its spatial environment. These included the grass *Hyparrhenia hirta,* which has a known redundancy for disturbed areas and is therefore negatively related to the sown treatments, which are generally more stable and resistant to invasion by outside species. Conversely, and somewhat contradictory, some non-sown species were stronger correlated with the sown treatments than with the control treatments on the graph (Figure 4.23). These species are *Nemesia fruticans*, *Oxalis latifolia*, *Cyperus esculentus* and *Eleusine coracana*. The former species, *N. fruticans,* is a perennial dwarf shrub (Germishuizen & Meyer 2003) and increased more than any other species (sown and non-sown) during the last season, indicating some secondary succession, mainly in the treated rip plots.

4.4.2.2. Ordination of plough treatment scores

The sown and non-sown species scores and their respective ploughed treatment scores are strongly correlated (r = 0.979) and are visible as three separate groupings (Figure 4.24) of which the seeded treatments and their grass mixture species are in close proximity as is the control treatment and the non-sown species. These correlations are stronger than during the first season (r = 0.764) and with the ripped treatments (r = 0.893) during the second season.

In contrast with the ripped treatments, where some non-sown species were correlated with the sown treatments, non-sown species (mainly weedy annuals) are particularly poorly correlated with the ploughed treatments and exceptionally well correlated with the control treatments. This indicates that the ploughed treatments reached, even within the third growing season, a fair degree of stability and that availability of resources to new entrant species is limited. It is however interesting to note the correlation between the perennial non-sown species *Nemesia fruticans* and the ploughed pasture treatments (Figure 4.24). The invasive species, *Hyparrhenia hirta*, was not recorded in the ploughed treatments up to the last recorded season. This is important as one of the objectives of this study is to monitor the presence of this highly invasive species onto old croplands (also see Chapter 2 Section 2.6.2.2. *Hyparrhenia hirta* Anthropogenic Grassland).

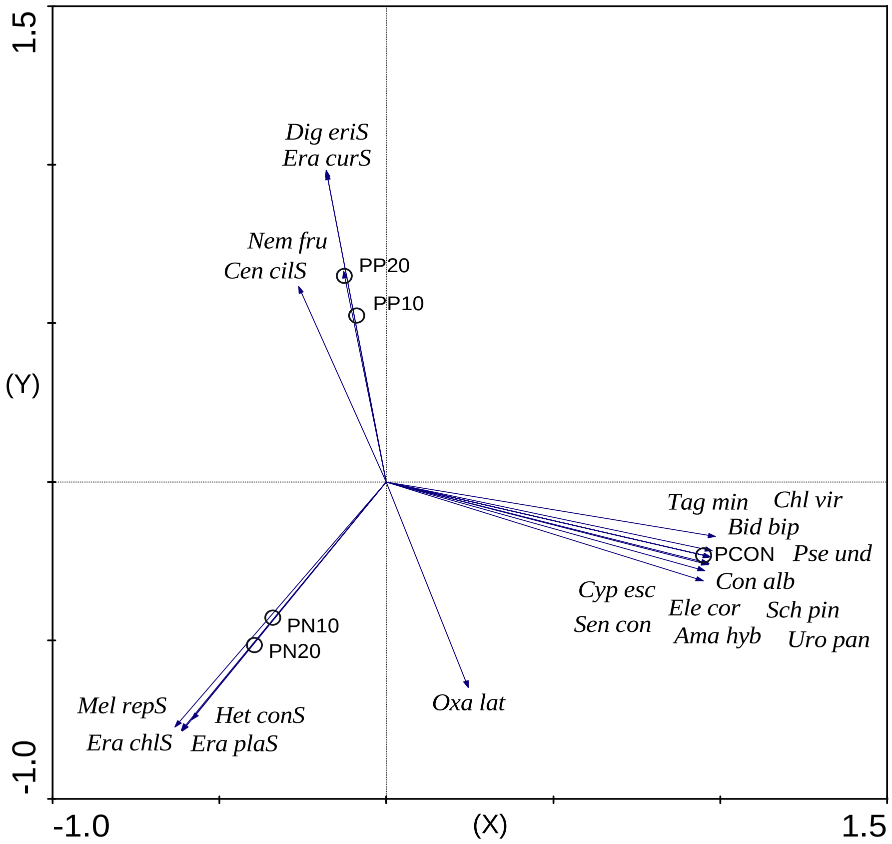

Figure 4.24: Principle Component Analysis ordination biplot showing correlations between treatment and species scores for ploughed treatments during the second recorded season (2005/06). Eigenvalues on the X- and Y- axes are 0.979 and 0.016 respectively. See Table 4.4 for species abbreviations.

4.5. Phytomass production

4.5.1. Phytomass production for ripped versus ploughed treatments

Although the plant density (sown and non-sown species combined) was the lowest in ploughed plots (Figure 4.25), the phytomass production, during both seasons, was the highest. The overall phytomass production increased from 310 g/m² in 2004/05 to 406 g/m² in 2005/06, which can mainly be ascribed to the increase in grass tuft sizes and a decrease in the less productive annual non-sown species. During the last season this phytomass almost exclusively consisted of the sown grasses. On the other hand, phytomass production for the control plots was mainly contributed by annual weeds (forbs) during both seasons.

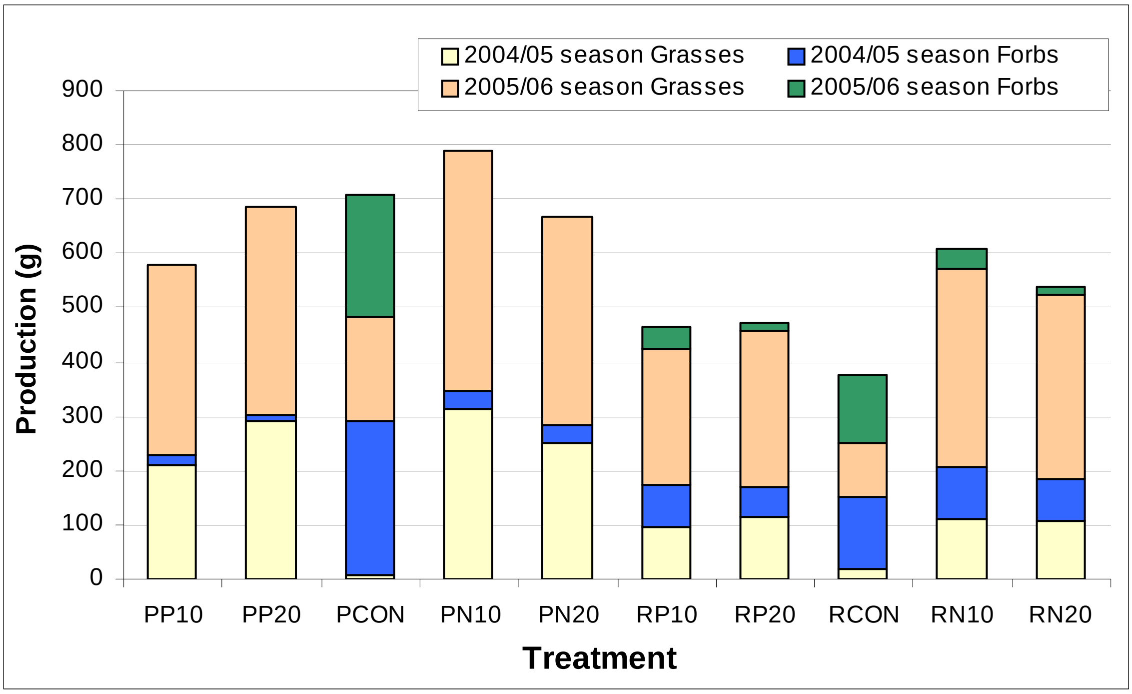

Figure 4.25: Phytomass production of grasses and forbs for all ten treatments during both recorded seasons. Phytomass production in ploughed plots was generally higher than in ripped plots with grass production being the main contributor. See Table 4.2 for treatment codes.

The treatment with the highest overall phytomass production for both seasons was PN10 (average 419.4 g/m^2) and the lowest was RCON (average 188.6 g/m^2) (Figure 4.25). Phytomass production in the ripped plots was generally lower than in the ploughed plots with a higher proportion phytomass from annual weeds (forbs) in these plots. As with the ploughed plots, phytomass production from grasses in the ripped plots increased substantially from 90 g/m^2 (2004/05 season) to 268 g/m^2 (2005/06 season).

The average above ground phytomass production during the second season was substantially higher (443.8 g/m^2) with the lower seeding rate of 10 kg seed/ha than with 20 kg seed/ha seeding rate (355.4 g/m^2), indicating improved availability of resources in the lower seeding rate treatments as appose to the higher seeding rate treatments.

Table 4.6: Phytomass production (g/m^2) for grasses and forbs for all ten treatments during both recording seasons, showing a reduction in forb (weed) phytomass and an increase in grass phytomass production. See Table 4.2 for treatment codes.

Treatments	2004/05 season			2005/06 season		Total
	Grasses	Forbs	Total	Grasses	Forbs	
PP10	209.00	18.50	227.50	352.13	0.00	352.13
PP20	292.90	10.10	303.00	382.14	0.00	382.14
PCON	8.88	282.38	291.25	191.73	225.86	417.59
PN10	313.13	35.13	348.25	489.88	0.75	490.63
PN20	249.00	33.30	282.30	385.70	0.00	385.70
Plough Average	**214.58**	**75.88**	**290.46**	**360.32**	**45.32**	**405.64**
RP10	97.50	76.13	173.63	251.13	39.88	405.64
RP20	114.43	56.57	171.00	286.13	14.00	300.13
RCON	19.38	130.88	150.25	99.75	127.25	227.00
RN10	109.86	97.71	207.57	365.50	36.25	527.13
RN20	106.50	78.25	184.75	337.88	15.88	353.75
Rip Average	89.53	87.91	177.44	268.08	46.65	362.73
Overall Average	**152.06**	**81.89**	**233.95**	**314.20**	**45.99**	**384.18**

4.5.2. Phytomass production between the two recorded seasons

The average phytomass production for all treatments combined increased from 244 g/m² in 2005 to 360 g/m² in 2006 (Table 4.6). This can mainly be attributed to a substantial increase in grass production, of which the phytomass production increased from 152 to 314 g/m² between the two seasons for all treatments combined. Conversely, the number of grass plants dropped from a high 91 to 64 ind/m². While the grass phytomass production increased (from a lower plant density), the forb phytomass production decreased from 82 g/m² to 46 g/m² between the two seasons to a reduction in plant density.

Although the overall phytomass production (g/m^2) for grasses was higher in the plough plots, the phytomass production per grass plant (g/ind) was substantially higher (10.13 g/plant vs. 7.83 g/plant) in the rip plots (Figure 4.26). The highest

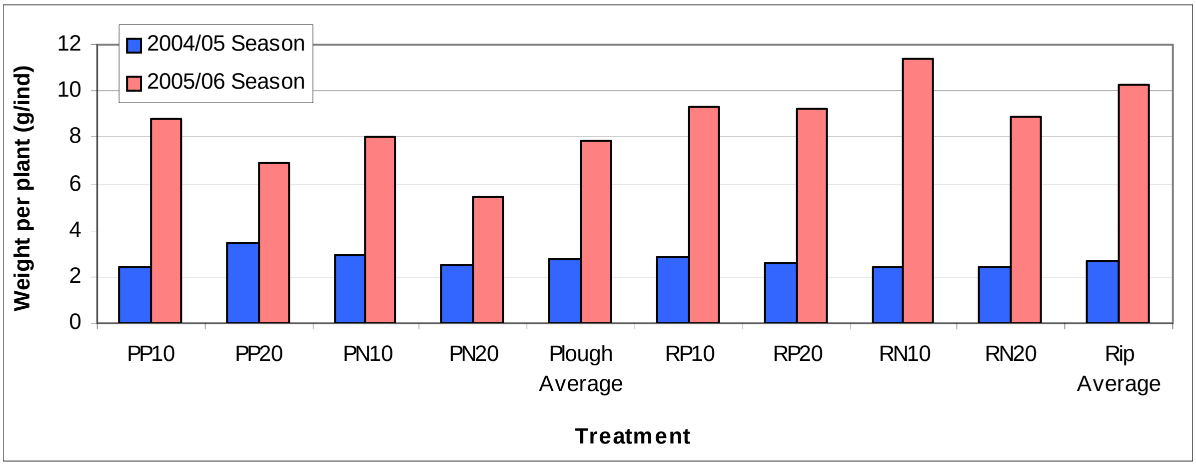

Figure 4.26: Phytomass production for grasses per plant (g/ind) for all treatments (control excluded) during the two recorded seasons.

average phytomass production per grass plant was sampled in the Rip 10 kg seed/ha plots (20.72 g/plant) and the lowest production in the Plough 20 kg seed/ha plots (12.38 g/plant). This was most likely caused by more available resources in the lower seed density rip plots in contrast to the densely populated higher seed density plough plots.

4.6. Soil analysis

This study did not focus on changes in physical and chemical soil properties, as these characteristics normally change slowly in time (Dormaar & Smoliak 1985, Jastrow 1987). Soil analyses of the cropland and natural rangeland were however done before establishment of the trials to investigate the need for fertilisation during establishment and to have soil data available for future research.

Only slight soil property differences occurred between the natural rangeland and cultivated land soils and suggested no drastic soil amendments. Noticeable differences, however, occurred between the Phosphate (P) and Organic Carbon contents as well as the Resistance (R) of the two soils (Table 4.7).

Most evident was the phosphate content, which was more than double in the cultivated area. The build up of this mineral can probably be ascribed to long-term phosphate fertilisation through past cropland management combined by the fact that phosphate generally leaches slowly though the soil profile. Peel (2004) mentions that where P is high, growth of grasses is likely to be vigorous, making it difficult for forbs to compete. This might also explain the good establishment of the sown grasses in this study or might even partly explain the dominance of *Hyparrhenia hirta* on old croplands.

Table 4.7: Soil analysis of the old cultivated lands (study site) and adjacent natural rangeland before establishment of the trials showing the main physical and chemical properties of the two soils.

Method used	**Bray 1**	**Ammonium acetate**									**Water**	**Hydrometer**			**Walkley Black**
Mineral	P	K	K	Ca	Ca	Mg	Mg	Na	Na	R	pH	Sand %	Silt %	Clay %	Org. C %
Measurement	mg/kg	mg/kg	mEq/100g	mg/kg	mEq/100g	mg/kg	mEq/100g	mg/kg	mEq/100g	ohm					
Natural Rangeland	11.5	291	0.744	803	4	194	1.6	10.5	0.046	1100	6.1	42.6	39.4	18	2.2
Cultivated area	23.8	297	0.758	598	3	116	0.96	16.8	0.073	2850	6	57.1	20.9	22	1.3

The formerly cultivated area is also significantly lower in organic carbon (1.3%) comparing to the natural rangeland (2.2%). It is generally accepted that cultivation of soil, which has previously supported native vegetation and/or pastures, generally leads to the decline of soil organic matter and carbon concentrations (Dalal & Mayer 1986), lower biological activity and deteriorating soil structure (Chan *et al.* 1992).

According to Post & Kwon (2000), much of the loss in soil organic carbon can be attributed to reduced inputs of organic matter, increased decomposability of crop residues, and tillage effects that decrease the amount of physical protection to decomposition. They also stated that soil organic carbon and N content would increase when previously cultivated soil is planted with permanent grasses. The average rate of accumulation of soil organic carbon is the same as for grassland, which is about 33 g C m^2/y^1.

The natural rangeland has a much lower electrical resistance (1100 ohm) than the cultivated area (2800 ohm), indicating a higher electrical conductivity in the adjacent natural rangeland due to a generally higher cationic content of the soil, which is usually caused by a higher content of minerals like Manganese (Mg^{2+}) and Calcium (Ca^{2+}).

4.7. Financial records

As an expense, the cost of seed contributed the most to the overall cost of establishing the trials (Table 4.8). The cost of seed for the two seed mixtures was almost similar and is presented below:

Pasture grasses =	R67.40/kg (VAT excluded)
Natural Grasses =	R65.00/kg (VAT excluded)

The plough method of establishment had three cultivation actions, namely ploughing, disking and rolling, and was therefore more expensive in terms of site preparation and seeding cost (R323/ha) than the ripping method, which tilled the soil and covered the seed in one action (R94/ha). The ultimate aim of the plough and broadcast method is to level the soil surface and prepare a fine seedbed before establishment. Any affordable alternatives can be considered. Specialised planters (Figure 1.2), which do seeding and covering in one action, will also reduce the cost of establishment during the plough method.

Labour for seeding in the lines for the rip method and for broadcasting during the plough method took about the same time and was calculated at about R50/ha. Labour for mechanisation is included in the mechanisation cost.

The most affordable restoration methods during these trials were the 10 kg seed/ha (pasture or natural grass seed) in the ripped section at R794/ha, while the most expensive treatments were the 20 kg seed/ha (pasture or natural grass seed) in the ploughed section at R1 721/ha (Table 4.8).

Table 4.8: Cost (ZAR/ha) of establishment of the ten treatments showing the RP10 and RN10 treatments to be the cheapest and the PP20 and PN20 treatments to be the most expensive. Rip, plough and disc cost include fuel and maintenance for a 75 KW tractor (see Appendix B for a breakdown of mechanisation costs).

Item/Treatment	PP10	PP20	PN10	PN20	RP10	RP20	RN10	RN20
Seed	674	1348	650	1300	674	1348	650	1300
Rip	0	0	0	0	94	94	94	94
Plough	175	175	175	175	0	0	0	0
Disc	106	106	106	106	0	0	0	0
Seed cover	42	42	42	42	0	0	0	0
Labour	50	50	50	50	50	50	50	50
Total (ZAR)	**1047**	**1721**	**1023**	**1673**	**818**	**1492**	**794**	**1444**

Although the cost and affordability of the various trials are important, the resemblance to natural rangeland in conservation areas is of primary concern. For instance, the rip method, which produced unnatural lines (Figure 4.4) in the restored areas, is unsuitable in conservation areas, although more affordable. The future challenge should be to make suitable methods cheaper.

Another factor that was not investigated in this study is the potential income that can be generated through restoration, for instance through grazing or producing fodder (e.g. hay). This is particularly important in agricultural areas, especially in developing countries, where restoration might not be an option if it does not make a contribution to socio-economic development (Aronson *et al.* 2006).

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

As outlined in Chapter 1, the aims of this study were to evaluate the various treatments in terms of establishment, weed control, resemblance to natural rangeland, secondary succession and establishing cost. These aims are concluded in this final chapter. This chapter also ends with recommendations for restoring old croplands as well as recommendations for future research on old cropland restoration in the Highveld region.

5.1. Establishment of the sown species

According to Aronson *et al.* (1993) the re-establishment of species and reconstitution of seed banks are crucial in promoting higher plant establishment and subsequent successful restoration. One of the outstanding features of this study was the good establishment of the two seed mixtures. The most important reasons for this general good establishment can be found in the establishment methods used, the relatively high seeding rates used and above average rainfall received. The time of establishment, namely towards the end of the growing season, also assisted in reducing relic weed competition levels during the first season.

5.1.1. Establishing methods

A comparison of the methods indicates that the plough method, although more costly, was more successful in establishing the sown species as well as controlling weed species than the rip method (Figures 4.4 and 4.5). This is mainly due to additional seedbed preparation and subsequent improved germination (Figure 4.1) obtained through broadcasting the seed on a fine seedbed (Figure 3.4).

The fact that the seed was broadcasted, instead of sown on narrow lines, as with the rip method (Figure 3.3), may also have caused lower levels of inter-plant competition among the sown species and therefore a overall higher seedling survival rate (Figure 4.1). Subsequently, by the end of the study period, there were higher sown species plant densities and phytomass production in the ploughed treatments (Figure 4.4 and 4.25). These conditions controlled weeds and resisted invasive plants successfully.

A noted disadvantage of the rip method, although more affordable, was the higher levels of weed (non-sown species) densities in comparison with the plough method (Table 4.3, Figures 4.5, 4.9 – 16). These higher levels of weed growth is probably due to the presence of open strips between the rip lines where more resources, like light, moisture and nutrients, were available for weed species to establish, survive and reproduce (Figure 4.11a).

It is interesting to note, however, that the higher occurrence of annual weeds in the rip plots during the last season were mainly in a vegetative stage, even though monitoring was carried out towards the end of the growing season when annual plants should have completed their life cycle. This indicates that the availability of resources (particularly light), even in the ripped plots, were extremely limited towards the third season due to the large size of sown perennial grasses. In the ploughed plots the sown grasses had almost completely out-competed weed species by the end of the trial. This can be better observed by the phytomass data (Figure 4.25 and Table 4.6) and, although subjective, the photographic records (Figures 4.9b – 16b).

5.1.2. Seed mixtures

Blumenthal *et al.* (2003) stated that local plant species should compete well against cropland weeds under local climatic and edaphic conditions during the restoration of formerly cultivated lands. Experimental studies have also found that late-successional plant communities may contain more competitive species and lower levels of available resources than early-successional plant communities (Vitousek & Walker 1987, Bazzaz 1996). Because early-successional species, such as agricultural weeds, are adapted to high levels of available resources (Baker 1965, Chapin 1980), they may be particularly unlikely to invade plant communities with low levels of available resources. The main above ground driving force influencing vegetation structure within grasslands in South Africa is competition for canopy space (which is related to light and moisture) among individual plants over time.

The choice, therefore, to include mainly intermediate (sub-climax) and late (climax) successional indigenous grass species, such as *Eragrostis curvula, Eragrostis chloromelas,* and *Digitaria eriantha*, in the seed mixtures, proved to be successful (even over this short time), in establishing late successional, mainly weed free, plant communities (Figures 4.9b – 16b).

Although the two seed mixtures (pasture and natural grass) generally produced equal plant densities and equally competed against the relic cropland weeds, there were noted differences in their vegetation structures and distribution pattern of species. These factors largely influence the resemblance of the restoration to the natural rangeland and are therefore extremely important in this particular study, being situated in a nature reserve (see section 5.2. on Resemblance to natural rangeland below).

In comparison to the seeded treatments, the control treatments were dominated by early successional plants, such as *Tagetes minuta* and *Urochloa panicoides*, even after three seasons (Table 4.3, Figures 4.5, 4.17 and 18), indicating the significance of successful reseeding.

The three *Eragrostis* species included within the two seed mixtures, *E. curvula, E. chloromelas* and *E. plana*, were the most dominant sown grasses in the trials throughout the study period (Table 4.4). A possible explanation for the dominance by these three sown species could be that, due to the small size of the seed, more seed of these species were included in their respective seed mixtures.

However, this dominance by a few species caused an inverse relationship between relative cover and general diversity in the trial. Baer *et al.* (2004) reported the same occurrence where *Panicum virgatum* (Switch grass) dominated the restoration. They suggest that restoration of croplands would benefit from reduced seeding rates of species that respond strongly to enhanced resource availability (such as formerly fertilised croplands), and are prone to dominate restored communities. Although the *Eragrostis* spp. dominated the sown treatments, and the restoration could have benefited from reduced seeding rates of these species, they are some of the most common species in the surrounding natural grassland.

Not all grasses established well. Two species, namely *Panicum maximum* (Buffalo grass) and *Cynodon dactylon* (Couch grass, Bermuda grass) did not establish well and decreased substantially in density towards the end of the trial (Table 4.4). Both these grasses have weedy characteristics (Bromilow 1996), which might indicate their decline over time, together with the other common cropland weeds. However, probably more accurate, is the fact that *P. maximum*, although locally present only in protected areas, is a tropical to sub-tropical plant and is not well adapted to open grassland conditions. *C. dactylon*, on the other hand, is locally common in disturbed areas, but is a low growing grass and easily suppressed by taller late successional grasses, such as the species included with *C. dactylon* in the seed mixture.

5.1.3. Seeding rates

There were generally little differences, in terms of establishment and plant density, between the two seeding rates (10 kg seed/ha and 20 kg seed/ha) used in this study (Table 4.1 and 4.5) and as a variable, produced the less significant results. The plant densities for both seeding rates decreased over time, indicating that generally high seeding rates were used. However, these high seeding rates might also be the reason why the seeded plots were generally successful in controlling the relict cropland weeds.

In retrospect, an additional lower seeding rate of 5 kg/ha, which would have produced lower plant densities, could have been included to test for weed control and secondary succession under these conditions and is therefore recommended for future research.

5.2. Resemblance to natural rangeland

5.2.1. Species composition and diversity

Natural grassland communities are generally dominated by a few species of perennial grasses, but also contain a large number of forbs (so-called satellite species) at low abundances. These satellite species contribute the most to the diversity of grassland (Collins & Barber 1985, Collins & Glenn 1990).

After 3 years, the restoration treatments at Suikerbosrand Nature Reserve were broadly similar to the natural grassland in the sense that indigenous perennial C_4 grasses (e.g. *Eragrostis chloromelas, E. curvula, Digitaria eriantha* and *Heteropogon contortus*) dominated the cover (Table 4.5, Figures 4.9 - 16). The restored grassland, however, was distinctly different from natural grassland with respect to the overall low representation of forbs in all the treatments. This lack of forb species is mainly due to the fact that no indigenous forb seed was available be included into either of the two seed mixtures. However, it is encouraging to note that some forb species, (e.g. *Nemesia fruticans* and *Senecio consanguineus*), occurred in some of the trials during the last season (Table 4.4) (also see section 5.3. on Secondary Succession below).

Many previous studies have noted the difficulty in establishing subdominant forb species in grassland restoration (Warkins & Howell 1983, Zajicek *et al.* 1986, Howe 1999, Jackson 1999). It is also cited that often the reintroduction of grasses into cultivated land is successful (Schramm 1990, Baer *et al.* 2002), but the establishment of forb species, which are critical for biodiversity in grasslands, is often inadequate (Kindscher & Tieszen 1998). According to Howe (1999) these forb species are vulnerable to local extinction in most grassland and should be incorporated as far as possible in restoration projects. It is therefore highly recommended that much effort in put into obtaining and including forb seed in cropland restoration projects and research, particularly in conservation areas.

5.2.2. Vegetation structure

Although the two seed mixtures used in this study were generally similar in terms of establishment and weed suppression, there was a marked difference in their resemblance to the nearby natural grassland in terms of vegetation structure. The natural grass seed mixture has structurally shown more resemblance to the natural grassland than the pasture grass mixture, even though the latter also consisted of indigenous grasses (Figures 4.17, 18 and 4.21, 22). This is most likely caused by the fact that the pasture grasses are all highly productive climax grasses while the natural grass mixture contains some early (*Melinis repens*), intermediate (*Heteropogon contortus*) and late (*Eragrostis chloromelas*) successional grasses, all with different production levels and growth habits. These differences gave an uneven vegetation structure, which resembles that of natural grassland more closely. The pasture grass mixture was also mainly dominated by one species (*Eragrostis curvula*), which gave more homogeneity in terms of vegetation structure and species distribution. Due to this the pasture grass restoration treatments resembled dryland pasture field's more than actual natural rangeland (Figures 4. 15 and 16).

Although the rip method of establishment is cheaper and may allow for faster seeding, a noted disadvantage is the elevated parallel lines caused by the rip action in the soil. These lines are also initially evident in the vegetation structure (Figures 4.11 and 12) due to the placement of seed. These elevated lines might render this method unacceptable for conservation areas where resemblance to the original natural system is of primary concern.

Conversely, the plough method “landscaped” the previously uneven cultivated soil more evenly and provided a smoother surface, which more closely resembles that of natural rangeland. Therefore, the plough method of site preparation will probably be more acceptable to be used in conservation areas. The rip method, being cheaper and faster, can be used with great success in situations where land users merely want to replenish the original seed bank and where resemblance to vegetation structure is of lesser importance.

For restoration of arable croplands, where forage production is more important than resemblance to natural grassland, the pasture mixture might proof more productive and still provide satisfying natural grassland resemblance. However, for restoration the aim should still be to create a diverse plant community.

5.3. Secondary succession

5.3.1. New entrant species

Although the open strips in the ripped plots hosted weedy annuals, at least during the early stages of the study, it has also shown that they facilitate establishment of new local non-sown perennial plants (Table 4.3). There was also a higher degree of new perennial plant occurrence in the lower seed densities (10 kg/ha) than in the higher seed densities (20 kg/ha), indicating more progressive successional changes in these lower seed densities. This can mainly be attributed to the higher levels of available resources in the ripped and lower seed density treatments.

It is also interesting to note that, similarly, in the control treatments, double the amount of new local perennial plants have established in the ripped control treatments than in the ploughed control treatments during the last season (Table 4.4). This indicates that not only the higher availability of resources in the open strips, but also the successional advantage of having no tillage (no disturbance) on the open strips caused more local perennial plants to establish in the rip treatments. It is possible that the combined open strips, and established grass lines (Figure 4.12a) perform, in terms of conditions for growth, the same functions as rangeland in a sub-climax condition, thereby creating suitable microsites for mid and late successional plants to establish. However, these microsites are also open to invasive species.

5.3.2. Resilience to invasive species

One of the new non-sown perennial plants entering some of the treatments was the tall grass *Hyparrhenia hirta* (Common Thatching Grass) (Figure 5.1). *H. hirta* is generally found on old croplands in the Highveld region of South Africa and is generally not associated with pristine grassland (Tainton & Hardy 1999, van Oudtshoorn 1999). Due to its wind dispersible seed, it is one of the first plants to colonise old lands. Furthermore, it's tall growth habit and dense tufts enable this grass to out-compete most other plants during secondary succession. Subsequently a succession stage with a low plant diversity, dominated by *Hyparrhenia hirta,*

Figure 5.1: An old land on Suikerbosrand Nature Reserve, showing gradual invasion of *Hyparrhenia hirta*.

follows. This stage can last for at least 50 years and more (Roux & Warren 1963, Bredenkamp & Brown 2003) (Also see section 2.6.2.2. *Hyparrhenia hirta* Anthropogenic Grassland)

Results from this study so far have shown that reseeding with the plough and broadcast method, which offers the lowest levels of available resources to invasive species, can control *H. hirta* invasion, at least in the short run (Figure 4.14). This lack of available resources to invasive plants were mainly due to high sown species densities and phytomass production in the ploughed treatments (Figures 4.4 and 4.25).

In the control plots, and to a lesser extent the ripped plots, where more resources were available, *H. hirta* gradually invaded towards the end of the trial (Table 4.4). However, as discussed above, the rip and control plots were also the hosts for other new perennial plants entering the treatments, thereby advancing secondary succession.

This situation, where the opportunity for heterogeneity (new perennials) and the threat of homogeneity (one invasive species) are competing for the same space, is causing considerable conflict. History has shown that *H. hirta* is a highly competitive species, especially on old cultivated lands, and that the smaller new entrant species can be easily out competed by its taller growth habit.

Assumption

In a study by Kindscher & Tieszen (1998), where plant community compositions was investigated 35 years after establishment of “successful” prairie restorations, it was revealed that the treatments have not returned, through secondary succession, to a condition similar to that of natural prairie. They pointed out that it is possible that these replanted prairies are reaching alternative stable states, based on the seed mixtures used during restoration.

Ehrenfeld (2000) stated that in many instances disturbed grasslands can be re-vegetated, but can never be completely restored. If this is true, and this study certainly suggests so, our best hope is to re-establish the complete species list based on the ecosystem of reference.

However, similarity to natural grassland is not only influenced by the re-establishment of particular plant species, as we did in this study, but also by the influence of fire (Blair 1997) and grazing (Knapp *et al.* 1999) on community structure and heterogeneity. Howe (1994, 1995 and 1999) also stated that variable fire regimes, grazing, and/or mowing may be required to maintain diversity in restored grassland communities in the long run.

The invasive grass *Hyparrhenia hirta* is also a so-called “Increaser I” species, which is defined as a grass which increases in number during conditions of under-grazing (Hurt *et al.* 1993, Bothma 1996, van Oudtshoorn 1999). Reseeding in combination with grazing might therefore be a method of controlling the density of *H. hirta* on restored croplands and need to be investigated. It is therefore suggested that fire frequency and grazing intensity be included in future research on restoration of previously cultivated areas.

5.4. Restoration cost

The most affordable restoration method used in this study, namely the 10 kg/ha seeding rate established by the rip method (both seed mixtures) (Table 4.8) did not produce satisfactory resemblance to natural rangeland (if the elevated soil lines are considered). The most affordable method with the closest resemblance to the natural rangeland was obtained by the natural grass mixture (10 kg/ha), established by the plough and broadcast method (Figure 5.2). It is recommended that this method should be used, but that cheaper ways of establishment further be investigated.

This will ask for a whole new outlook at the importance and possibilities of ecological restoration in South Africa. Old cropland restoration is generally unaffordable to most landowners and financial incentives, subsidies or any other support from authorities and/or other stakeholders might be necessary before large-scale restoration will commence.

In a recent study by Aronson *et al.* (2006) they point out that restoration is in fact complementary not only to nature conservation but also to sustainable, equitable socio-economic development. This is because restoring and augmenting the natural capital base generates jobs and improves livelihoods and the quality of life of all in the economy. At the rate that pristine grassland is currently lost to development in the Highveld region, the restoration of abandoned croplands might become a necessity, instead of merely an option.

Figure 5.2. The most affordable restoration method, that produced the nearest resemblance to the nearby natural grassland, was the plough and broadcast establishing method in combination with the natural grass seed mixture at a 10 kg seed/ha seeding rate.

5.5. Recommendations

The following recommendations are made for old cropland restoration and future research in the highveld region of South Africa:

5.5.1. Restoration recommendations

5.5.1.1. Implementation of restoration

- If clear cultivation ridges and lines are visible, it should preferably be leveled to create a smooth soil surface.
- A fine seedbed, to facilitate germination of small seed, should be prepared.
- Group seed according to their shape and size. Mix the seed properly before broadcasting. If broadcasting is done by hand, sand should be added to small seed to assist with evenly broadcasting the seed.
- After broadcasting, the seed should be slightly covered (e.g. by using a roller) to improve seed and soil contact and to reduce predation on seed.

5.5.1.2. Time of implementation

- Establishment should be done from November to February. Results from this study suggest that establishment during early February has an advantage in terms of weed control, provided adequate moisture is available for germination and establishment of the sown species. Recommendations for establishing planted pastures could be followed in this regard.

5.5.1.3. Seeding density

- The seeding density should be about 10 kg seed/ha. A lower density might lead to *Hyparrhenia hirta* invasion. However, further research is needed on lower densities.

5.5.1.4. Seed mixtures

- As much as possible seed of plants occurring in the ecosystem of reference should be added to the seed mixture. Seed of the same ecotypes occurring in the area should be best adapted to the prevailing environmental conditions and pose the least threat to genetic contamination.

- It is recommended that invasive species (e.g. *Hyparrhenia hirta* and *Stoebe vulgaris*) not be included in seed mixtures in the Highveld region.
- If not commercially available the seed could be collected in undisturbed natural rangeland within the same vegetation unit and nearest to the restoration site as possible. Seed
- The species ratios of seed in the seed mixture should be according to the species composition in the ecosystem of reference.
- The size of seed (number of seed/100g), germination percentage and purity of seed samples should be taken in account when calculating seed ratios for seed mixtures.

5.5.1.5. Restoration management

- As the effect of fire and grazing on newly restored areas is not known, it is recommended that newly restored areas not be subjected to fire, for at least three full seasons, and grazing, for at least two seasons after establishment.

5.5.2. Future research

It is recommended that future research on old cropland restoration in the grassland biome of South Africa investigate the following aspects:

- The affordability and effectiveness of various land preparation and establishing methods, which produce similar results to the plough and broadcast method used in this study, should be tested. This should include seeding machines that can deal with seed of different shapes and sizes and the methods tested should be able to restore large areas (> 50 ha).
- Methods for successfully harvesting seed of grassland species (grass and forbs) in natural rangeland. As the cost of seed makes up the largest part of cropland restoration establishing cost, the affordability of these methods should be considered.
- Grasses tend to dominate forbs when seed ratios are not correct (Kilde & Fuge 2000). Therefore, to get general guidelines for South African grassland, different seed ratios for seed mixtures need to be investigated. As mentioned above, the size of seed (number of seed/100g), the germination percentage of

seed, the purity of seed samples and the competitiveness of species should be taken in account when calculating seed ratios. Ultimately the seed mixtures, with the various seed ratios, should produce comparable results to the species composition of the ecosystem of reference.

- Various seeding densities should be tested to investigate the effect of seeding density on relic cropland weed control, resistance to perennial invasive species and establishment of sown forb species. It is recommended that various seeding densities between 3 to 15 kg seed/ha be tested.
- The effect of different fire intensity regimes on species composition, species diversity, plant community structure, distribution pattern of species, carbon and nutrient cycling as well as phytomass production, comparing to the ecosystem of reference, should be tested.
- The effect of different levels of grazing pressure on species composition, species diversity, plant community structure, distribution pattern of species, carbon and nutrient cycling and grazing capacity comparing to the ecosystem of reference.
- The influence of unbalanced soil chemical levels, typical to old lands because of long-term fertilization, on restoration should be tested. Also measures to reduce minerals and chemicals that accumulated during crop production should be investigated.
- Changes in soil properties in restored cropland over time. Specifically in terms of organic carbon content, microbe concentration, nitrogen cycling, aggregate formation and mineral content.
- Various chemical weed control methods should be tested on relic weed control and successful restoration establishment. The residual effect of herbicides on the ecology should also be considered.
- The effect of old cropland restoration on socio-economic development needs to be investigated. Different forms of land use for restored croplands need to be explored in terms of economic potential in combination with biodiversity conservation.

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APPENDICES

Appendix A

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Restoration trials 2004-2006


===== Season      2004/05       =====


***** Analysis of variance *****

Variate: Sown

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

REP stratum                1     32724.     32724.    2.86

REP.PLOT stratum
TMT                        9   1068533.    118726.   10.37  <.001
Residual                   9    103059.     11451.

Total                     19   1204317.


***** Tables of means *****

Variate: Sown

Grand mean  374.

      TMT        PC     PP10     PP20     PV10     PV20        RC     RP10
               100.     703.     684.     525.     602.        0.     273.

      TMT      RP20     RV10     RV20
               348.     238.     268.


*** Standard errors of means ***

Table                  TMT
rep.                     2
d.f.                     9
e.s.e.                75.7

*** Least significant differences of means (5% level) ***

Table                  TMT
rep.                     2
d.f.                     9
l.s.d.               242.1


***** Stratum standard errors and coefficients of variation *****

Variate: Sown

Stratum                    d.f.          s.e.         cv%
```

REP	1	57.2	15.3
REP.PLOT	9	107.0	28.6

All pairwise comparisons are tested.

Variance =   11451.0500 with   9 degrees of freedom

Fisher's Protected Least Significant Difference test

```
       Experimentwise error rate =   0.0500
 F value is    10.37  on      9  &      9  degrees of freedom
 Overall F test is significant, pairwise testing proceeds.

       Comparisonwise error rate =   0.0500

 Identifier        Mean

       PP10       703.0 |
       PP20       683.5 |
       PV20       601.5 |
       PV10       525.0 | |
       RP20       348.5   | |
       RP10       273.0     | |
       RV20       267.5     | |
       RV10       237.5     | | |
         PC        99.5       | |
         RC         0.5         |
```

========== Summary of original data ==========

TMT	Nobservd	Mean	Variance
PC	2	99.5	19012
PP10	2	703.0	16562
PP20	2	683.5	22260
PV10	2	525.0	32768
PV20	2	601.5	38920
RC	2	0.5	0
RP10	2	273.0	722
RP20	2	348.5	4512
RV10	2	237.5	544
RV20	2	267.5	480

SEASON	REP	TMT	Sown	FITTED	RESIDUAL
04/05	1	PC	197.0	139.9	57.05
04/05	2	PC	2.0	59.1	-57.05
04/05	1	PP10	794.0	743.5	50.55
04/05	2	PP10	612.0	662.5	-50.55
04/05	1	PP20	789.0	724.0	65.05
04/05	2	PP20	578.0	643.0	-65.05
04/05	1	PV10	397.0	565.5	-168.45
04/05	2	PV10	653.0	484.6	168.45
04/05	1	PV20	741.0	642.0	99.05
04/05	2	PV20	462.0	561.0	-99.05

```
     04/05         1         RC       1.0      40.9    -39.95
     04/05         2         RC       0.0     -39.9     39.95
     04/05         1       RP10     292.0     313.4    -21.45
     04/05         2       RP10     254.0     232.6     21.45
     04/05         1       RP20     396.0     388.9      7.05
     04/05         2       RP20     301.0     308.1     -7.05
     04/05         1       RV10     254.0     277.9    -23.95
     04/05         2       RV10     221.0     197.1     23.95
     04/05         1       RV20     283.0     307.9    -24.95
     04/05         2       RV20     252.0     227.1     24.95


      ===== Season      2004/05       =====


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***** Analysis of variance *****

Variate: Nonsown

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

REP stratum                1    156645.    156645.    1.94

REP.PLOT stratum
TMT                        9   7468500.    829833.   10.30  <.001
Residual                   9    724952.     80550.

Total                     19   8350097.


***** Tables of means *****

Variate: Nonsown

Grand mean  938.

      TMT        PC      PP10      PP20      PV10      PV20        RC      RP10
              2245.      428.      144.      642.      404.     1662.      750.

      TMT      RP20      RV10      RV20
               720.     1313.     1069.


*** Standard errors of means ***

Table                    TMT
rep.                       2
d.f.                       9
e.s.e.                 200.7

*** Least significant differences of means (5% level) ***

Table                    TMT
rep.                       2
d.f.                       9
l.s.d.                 642.0
```

***** Stratum standard errors and coefficients of variation *****

Variate: Nonsown

Stratum	d.f.	s.e.	cv%
REP	1	125.2	13.3
REP.PLOT	9	283.8	30.3

All pairwise comparisons are tested.

Variance = 80550.2222 with 9 degrees of freedom

Fisher's Protected Least Significant Difference test

```
        Experimentwise error rate =   0.0500
 F value is    10.30  on      9  &      9  degrees of freedom
 Overall F test is significant, pairwise testing proceeds.

        Comparisonwise error rate =   0.0500

 Identifier        Mean

         PC      2245.0 |
         RC      1661.5 | |
       RV10      1313.0   | |
       RV20      1069.0   | | |
       RP10       750.5     | | |
       RP20       720.5     | | |
       PV10       641.5       | |
       PP10       428.5       | |
       PV20       404.0         |
       PP20       144.5         |
```

========== Summary of original data ==========

TMT	Nobservd	Mean	Variance
PC	2	2245.0	638450
PP10	2	428.5	122512
PP20	2	144.5	11704
PV10	2	641.5	5724
PV20	2	404.0	20000
RC	2	1661.5	65884
RP10	2	750.5	2244
RP20	2	720.5	144
RV10	2	1313.0	12482
RV20	2	1069.0	2450

SEASON	REP	TMT	Nonsown	FITTED	RESIDUAL
04/05	1	PC	1680.0	2156.5	-476.5
04/05	2	PC	2810.0	2333.5	476.5
04/05	1	PP10	676.0	340.0	336.0
04/05	2	PP10	181.0	517.0	-336.0

04/05	1	PP20	68.0	56.0	12.0
04/05	2	PP20	221.0	233.0	-12.0
04/05	1	PV10	588.0	553.0	35.0
04/05	2	PV10	695.0	730.0	-35.0
04/05	1	PV20	304.0	315.5	-11.5
04/05	2	PV20	504.0	492.5	11.5
04/05	1	RC	1480.0	1573.0	-93.0
04/05	2	RC	1843.0	1750.0	93.0
04/05	1	RP10	717.0	662.0	55.0
04/05	2	RP10	784.0	839.0	-55.0
04/05	1	RP20	712.0	632.0	80.0
04/05	2	RP20	729.0	809.0	-80.0
04/05	1	RV10	1234.0	1224.5	9.5
04/05	2	RV10	1392.0	1401.5	-9.5
04/05	1	RV20	1034.0	980.5	53.5
04/05	2	RV20	1104.0	1157.5	-53.5

===== Season 2004/05 =====

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***** Analysis of variance *****

Variate: Total

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	46176.	46176.	0.54	
REP.PLOT stratum					
TMT	9	3540536.	393393.	4.61	0.016
Residual	9	768345.	85372.		
Total	19	4355058.			

***** Tables of means *****

Variate: Total

Grand mean 1312.

TMT	PC	PP10	PP20	PV10	PV20	RC	RP10
	2344.	1132.	828.	1166.	1006.	1662.	1024.

TMT	RP20	RV10	RV20
	1069.	1550.	1336.

*** Standard errors of means ***

Table	TMT
rep.	2
d.f.	9
e.s.e.	206.6

*** Least significant differences of means (5% level) ***

```
Table                  TMT
rep.                     2
d.f.                     9
l.s.d.               661.0

***** Stratum standard errors and coefficients of variation *****

Variate: Total

Stratum                   d.f.          s.e.         cv%

REP                          1          68.0         5.2
REP.PLOT                     9         292.2        22.3


 All pairwise comparisons are tested.


 Variance =    85371.7167  with    9  degrees of freedom

 Fisher's Protected Least Significant Difference test


        Experimentwise error rate =   0.0500
  F value is     4.61  on      9  &      9  degrees of freedom
  Overall F test is significant, pairwise testing proceeds.

        Comparisonwise error rate =   0.0500

  Identifier        Mean

          PC        2344
          RC        1662 |
        RV10        1550 |
        RV20        1336 | |
        PV10        1166 | |
        PP10        1132 | |
        RP20        1069 | |
        RP10        1024 | |
        PV20        1006 | |
        PP20         828   |


 ========== Summary of original data ==========


             Nobservd        Mean    Variance
         TMT
          PC          2        2344      437112
        PP10          2        1132      229164
        PP20          2         828        1682
        PV10          2        1166       65884
        PV20          2        1006        3120
          RC          2        1662       65522
        RP10          2        1024         420
        RP20          2        1069        3042
        RV10          2        1550        7812
        RV20          2        1336         760
```

SEASON	REP	TMT	Total	FITTED	RESIDUAL
04/05	1	PC	1877	2296	-419.5
04/05	2	PC	2812	2393	419.5
04/05	1	PP10	1470	1083	386.5
04/05	2	PP10	793	1180	-386.5
04/05	1	PP20	857	780	77.1
04/05	2	PP20	799	876	-77.0
04/05	1	PV10	985	1118	-133.4
04/05	2	PV10	1348	1215	133.4
04/05	1	PV20	1045	957	87.6
04/05	2	PV20	966	1054	-87.6
04/05	1	RC	1481	1614	-132.9
04/05	2	RC	1843	1710	132.9
04/05	1	RP10	1009	975	33.6
04/05	2	RP10	1038	1072	-33.6
04/05	1	RP20	1108	1021	87.1
04/05	2	RP20	1030	1117	-87.1
04/05	1	RV10	1488	1502	-14.4
04/05	2	RV10	1613	1599	14.4
04/05	1	RV20	1317	1288	28.5
04/05	2	RV20	1356	1385	-28.5

===== Season 2005/06 =====

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***** Analysis of variance *****

Variate: Sown

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	9548.	9548.	4.97	
REP.PLOT stratum					
TMT	9	337032.	37448.	19.50	<.001
Residual	9	17284.	1920.		
Total	19	363865.			

***** Tables of means *****

Variate: Sown

Grand mean 229.4

TMT	PC	PP10	PP20	PV10	PV20	RC	RP10
	34.5	319.5	443.0	281.5	373.0	9.0	219.5

TMT	RP20	RV10	RV20
	244.0	167.0	203.5

*** Standard errors of means ***

Table TMT

```
rep.                      2
d.f.                      9
e.s.e.                30.99

*** Least significant differences of means (5% level) ***

Table                   TMT
rep.                      2
d.f.                      9
l.s.d.                99.13


***** Stratum standard errors and coefficients of variation *****

Variate: Sown

Stratum                    d.f.          s.e.         cv%

REP                           1         30.90        13.5
REP.PLOT                      9         43.82        19.1



 All pairwise comparisons are tested.


 Variance =     1920.4500  with    9  degrees of freedom

 Fisher's Protected Least Significant Difference test


         Experimentwise error rate =   0.0500
  F value is    19.50  on      9  &      9  degrees of freedom
  Overall F test is significant, pairwise testing proceeds.

         Comparisonwise error rate =   0.0500

  Identifier        Mean

         PP20       443.0 |
         PV20       373.0 | |
         PP10       319.5   | |
         PV10       281.5   | | |
         RP20       244.0     | | |
         RP10       219.5       | |
         RV20       203.5       | |
         RV10       167.0         |
           PC        34.5           |
           RC         9.0           |


 ========== Summary of original data ==========


                Nobservd        Mean    Variance
          TMT
           PC          2        34.5        1740
         PP10          2       319.5        2812
         PP20          2       443.0        5832
         PV10          2       281.5           0
         PV20          2       373.0        7442
```

RC	2	9.0	162
RP10	2	219.5	5304
RP20	2	244.0	1352
RV10	2	167.0	1922
RV20	2	203.5	264

SEASON	REP	TMT	Sown	FITTED	RESIDUAL
05/06	1	PC	64.0	56.4	7.65
05/06	2	PC	5.0	12.7	-7.65
05/06	1	PP10	282.0	341.4	-59.35
05/06	2	PP10	357.0	297.6	59.35
05/06	1	PP20	497.0	464.9	32.15
05/06	2	PP20	389.0	421.1	-32.15
05/06	1	PV10	282.0	303.4	-21.35
05/06	2	PV10	281.0	259.6	21.35
05/06	1	PV20	434.0	394.9	39.15
05/06	2	PV20	312.0	351.1	-39.15
05/06	1	RC	0.0	30.9	-30.85
05/06	2	RC	18.0	-12.8	30.85
05/06	1	RP10	271.0	241.3	29.65
05/06	2	RP10	168.0	197.7	-29.65
05/06	1	RP20	270.0	265.9	4.15
05/06	2	RP20	218.0	222.2	-4.15
05/06	1	RV10	198.0	188.8	9.15
05/06	2	RV10	136.0	145.2	-9.15
05/06	1	RV20	215.0	225.3	-10.35
05/06	2	RV20	192.0	181.7	10.35

===== Season 2005/06 =====

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***** Analysis of variance *****

Variate: Nonsown

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	8405.	8405.	0.04	
REP.PLOT stratum					
TMT	9	12435495.	1381722.	5.86	0.007
Residual	9	2121206.	235690.		
Total	19	14565106.			

***** Tables of means *****

Variate: Nonsown

Grand mean 838.

TMT	PC	PP10	PP20	PV10	PV20	RC	RP10
	1220.	56.	40.	242.	231.	2809.	1090.

TMT	RP20	RV10	RV20

```
              961.     608.    1126.


*** Standard errors of means ***

Table                  TMT
rep.                     2
d.f.                     9
e.s.e.               343.3

*** Least significant differences of means (5% level) ***

Table                  TMT
rep.                     2
d.f.                     9
l.s.d.              1098.2


***** Stratum standard errors and coefficients of variation *****

Variate: Nonsown

Stratum                    d.f.          s.e.         cv%

REP                           1          29.0         3.5
REP.PLOT                      9         485.5        57.9



 All pairwise comparisons are tested.


 Variance =   235689.5556  with    9  degrees of freedom

 Fisher's Protected Least Significant Difference test


         Experimentwise error rate =   0.0500
  F value is     5.86  on      9  &      9  degrees of freedom
  Overall F test is significant, pairwise testing proceeds.

         Comparisonwise error rate =   0.0500

  Identifier        Mean

           RC      2809.0
           PC      1220.5 |
         RV20      1126.0 | |
         RP10      1089.5 | |
         RP20       961.0 | |
         RV10       608.5 | |
         PV10       241.5 | |
         PV20       231.0 | |
         PP10        56.5   |
         PP20        39.5   |


 ========== Summary of original data ==========


                 Nobservd        Mean    Variance
```

TMT			
PC	2	1220.5	104424
PP10	2	56.5	5100
PP20	2	39.5	220
PV10	2	241.5	12324
PV20	2	231.0	2178
RC	2	2809.0	354482
RP10	2	1089.5	1256112
RP20	2	961.0	163592
RV10	2	608.5	18624
RV20	2	1126.0	212552

SEASON	REP	TMT	Nonsown	FITTED	RESIDUAL
05/06	1	PC	1449.0	1200.0	249.0
05/06	2	PC	992.0	1241.0	-249.0
05/06	1	PP10	107.0	36.0	71.0
05/06	2	PP10	6.0	77.0	-71.0
05/06	1	PP20	29.0	19.0	10.0
05/06	2	PP20	50.0	60.0	-10.0
05/06	1	PV10	163.0	221.0	-58.0
05/06	2	PV10	320.0	262.0	58.0
05/06	1	PV20	264.0	210.5	53.5
05/06	2	PV20	198.0	251.5	-53.5
05/06	1	RC	3230.0	2788.5	441.5
05/06	2	RC	2388.0	2829.5	-441.5
05/06	1	RP10	297.0	1069.0	-772.0
05/06	2	RP10	1882.0	1110.0	772.0
05/06	1	RP20	675.0	940.5	-265.5
05/06	2	RP20	1247.0	981.5	265.5
05/06	1	RV10	512.0	588.0	-76.0
05/06	2	RV10	705.0	629.0	76.0
05/06	1	RV20	1452.0	1105.5	346.5
05/06	2	RV20	800.0	1146.5	-346.5

===== Season 2005/06 =====

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***** Analysis of variance *****

Variate: Total

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	36.	36.	0.00	
REP.PLOT stratum					
TMT	9	9324504.	1036056.	4.72	0.015
Residual	9	1976297.	219589.		
Total	19	11300838.			

***** Tables of means *****

Variate: Total

```
Grand mean  1068.

      TMT        PC      PP10      PP20      PV10      PV20        RC      RP10
              1255.      376.      482.      523.      604.     2818.     1309.

      TMT      RP20      RV10      RV20
              1205.      776.     1330.


*** Standard errors of means ***

Table                  TMT
rep.                     2
d.f.                     9
e.s.e.               331.4

*** Least significant differences of means (5% level) ***

Table                  TMT
rep.                     2
d.f.                     9
l.s.d.              1060.1


***** Stratum standard errors and coefficients of variation *****

Variate: Total

Stratum                     d.f.           s.e.         cv%

REP                            1            1.9         0.2
REP.PLOT                       9          468.6        43.9



 All pairwise comparisons are tested.


 Variance =   219588.5611  with    9  degrees of freedom

 Fisher's Protected Least Significant Difference test


         Experimentwise error rate =   0.0500
  F value is     4.72  on      9  &      9  degrees of freedom
  Overall F test is significant, pairwise testing proceeds.

         Comparisonwise error rate =   0.0500

  Identifier        Mean

           RC        2818
         RV20        1330 |
         RP10        1309 |
           PC        1255 |
         RP20        1205 |
         RV10         776 |
         PV20         604 |
         PV10         523 |
         PP20         482 |
         PP10         376 |
```

========== Summary of original data ==========

TMT	Nobservd	Mean	Variance
PC	2	1255	133128
PP10	2	376	338
PP20	2	482	3784
PV10	2	523	12168
PV20	2	604	17672
RC	2	2818	339488
RP10	2	1309	1098162
RP20	2	1205	135200
RV10	2	776	8580
RV20	2	1330	227812

SEASON	REP	TMT	Total	FITTED	RESIDUAL
05/06	1	PC	1513	1256	256.6
05/06	2	PC	997	1254	-256.6
05/06	1	PP10	389	377	11.6
05/06	2	PP10	363	375	-11.6
05/06	1	PP20	526	484	42.1
05/06	2	PP20	439	481	-42.1
05/06	1	PV10	445	524	-79.4
05/06	2	PV10	601	522	79.4
05/06	1	PV20	698	605	92.6
05/06	2	PV20	510	603	-92.6
05/06	1	RC	3230	2819	410.7
05/06	2	RC	2406	2817	-410.7
05/06	1	RP10	568	1310	-742.4
05/06	2	RP10	2050	1308	742.4
05/06	1	RP20	945	1206	-261.4
05/06	2	RP20	1465	1204	261.4
05/06	1	RV10	710	777	-66.9
05/06	2	RV10	841	774	66.8
05/06	1	RV20	1667	1331	336.1
05/06	2	RV20	992	1328	-336.1

=============== Two seasons combined ================

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***** Analysis of variance *****

Variate: Sown

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
YEAR stratum					
SEASON	1	208802.	208802.		
YEAR.REP stratum	2	42273.	21136.	3.16	
YEAR.REP.PLOT stratum					

```
TMT                          9   1270805.    141201.   21.12  <.001
SEASON.TMT                   9    134760.     14973.    2.24  0.069
Residual                    18    120344.      6686.

Total                       39   1776984.


***** Tables of means *****

Variate: Sown

Grand mean  302.

   SEASON    04/05    05/06
              374.     229.

      TMT       PC     PP10     PP20     PV10     PV20       RC     RP10
               67.     511.     563.     403.     487.       5.     246.

      TMT     RP20     RV10     RV20
              296.     202.     236.

   SEASON      TMT       PC     PP10     PP20     PV10     PV20       RC
    04/05               99.     703.     684.     525.     602.       0.
    05/06               34.     320.     443.     282.     373.       9.

   SEASON      TMT     RP10     RP20     RV10     RV20
    04/05              273.     348.     238.     268.
    05/06              220.     244.     167.     204.


*** Standard errors of means ***

Table                 SEASON         TMT      SEASON
                                                 TMT
rep.                      20           4           2
d.f.                       *          18           *
e.s.e.                     *        40.9           *
Except when comparing means with the same level(s) of
 SEASON                                         57.8

*** Least significant differences of means (5% level) ***

Table                 SEASON         TMT      SEASON
                                                 TMT
rep.                      20           4           2
d.f.                       *          18           *
l.s.d.                     *       121.5           *
Except when comparing means with the same level(s) of
 SEASON                                        171.8


***** Stratum standard errors and coefficients of variation *****

Variate: Sown

Stratum                    d.f.          s.e.         cv%

YEAR                          0             *           *
YEAR.REP                      2          46.0        15.2
YEAR.REP.PLOT                18          81.8        27.1
```

```
========== Summary of original data ==========

      TMT         PC
            Nobservd        Mean    Variance
   SEASON
    04/05          2        99.5       19012
    05/06          2        34.5        1740

   Margin          4        67.0        8326


      TMT       PP10
            Nobservd        Mean    Variance
   SEASON
    04/05          2       703.0       16562
    05/06          2       319.5        2812

   Margin          4       511.2       55482


      TMT       PP20
            Nobservd        Mean    Variance
   SEASON
    04/05          2       683.5       22260
    05/06          2       443.0        5832

   Margin          4       563.2       28644


      TMT       PV10
            Nobservd        Mean    Variance
   SEASON
    04/05          2       525.0       32768
    05/06          2       281.5           0

   Margin          4       403.2       30687


      TMT       PV20
            Nobservd        Mean    Variance
   SEASON
    04/05          2       601.5       38920
    05/06          2       373.0        7442

   Margin          4       487.2       32858


      TMT         RC
            Nobservd        Mean    Variance
   SEASON
    04/05          2         0.5           0
    05/06          2         9.0         162

   Margin          4         4.8          78


      TMT       RP10
```

	Nobservd	Mean	Variance
SEASON			
04/05	2	273.0	722
05/06	2	219.5	5304
Margin	4	246.2	2963

TMT	RP20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	348.5	4512
05/06	2	244.0	1352
Margin	4	296.2	5595

TMT	RV10		
	Nobservd	Mean	Variance
SEASON			
04/05	2	237.5	544
05/06	2	167.0	1922
Margin	4	202.2	2479

TMT	RV20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	267.5	480
05/06	2	203.5	264
Margin	4	235.5	1614

TMT	Margin		
	Nobservd	Mean	Variance
SEASON			
04/05	20	373.9	63385
05/06	20	229.5	19151
Margin	40	301.7	45564

SEASON	REP	TMT	Sown	FITTED	RESIDUAL
04/05	1	PC	197.0	140.0	57.05
04/05	2	PC	2.0	59.0	-57.05
04/05	1	PP10	794.0	743.5	50.55
04/05	2	PP10	612.0	662.5	-50.55
04/05	1	PP20	789.0	724.0	65.05
04/05	2	PP20	578.0	643.0	-65.05
04/05	1	PV10	397.0	565.5	-168.45
04/05	2	PV10	653.0	484.5	168.45
04/05	1	PV20	741.0	642.0	99.05
04/05	2	PV20	462.0	561.0	-99.05
04/05	1	RC	1.0	41.0	-39.95
04/05	2	RC	0.0	-40.0	39.95
04/05	1	RP10	292.0	313.5	-21.45
04/05	2	RP10	254.0	232.5	21.45
04/05	1	RP20	396.0	389.0	7.05
04/05	2	RP20	301.0	308.0	-7.05

04/05	1	RV10	254.0	278.0	-23.95
04/05	2	RV10	221.0	197.0	23.95
04/05	1	RV20	283.0	308.0	-24.95
04/05	2	RV20	252.0	227.0	24.95
05/06	1	PC	64.0	56.3	7.65
05/06	2	PC	5.0	12.7	-7.65
05/06	1	PP10	282.0	341.4	-59.35
05/06	2	PP10	357.0	297.6	59.35
05/06	1	PP20	497.0	464.9	32.15
05/06	2	PP20	389.0	421.1	-32.15
05/06	1	PV10	282.0	303.4	-21.35
05/06	2	PV10	281.0	259.6	21.35
05/06	1	PV20	434.0	394.9	39.15
05/06	2	PV20	312.0	351.1	-39.15
05/06	1	RC	0.0	30.8	-30.85
05/06	2	RC	18.0	-12.8	30.85
05/06	1	RP10	271.0	241.3	29.65
05/06	2	RP10	168.0	197.7	-29.65
05/06	1	RP20	270.0	265.9	4.15
05/06	2	RP20	218.0	222.2	-4.15
05/06	1	RV10	198.0	188.8	9.15
05/06	2	RV10	136.0	145.2	-9.15
05/06	1	RV20	215.0	225.3	-10.35
05/06	2	RV20	192.0	181.7	10.35

=============== Two seasons combined =================

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***** Analysis of variance *****

Variate: Nonsown

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
YEAR stratum					
SEASON	1	99003.	99003.		
YEAR.REP stratum	2	165050.	82525.	0.52	
YEAR.REP.PLOT stratum					
TMT	9	16624973.	1847219.	11.68	<.001
SEASON.TMT	9	3279022.	364336.	2.30	0.063
Residual	18	2846158.	158120.		
Total	39	23014206.			

***** Tables of means *****

Variate: Nonsown

Grand mean 888.

SEASON	04/05	05/06
	938.	838.

```
      TMT        PC      PP10      PP20      PV10      PV20        RC      RP10
              1733.      242.       92.      441.      318.     2235.      920.

      TMT      RP20      RV10      RV20
               841.      961.     1098.

   SEASON       TMT        PC      PP10      PP20      PV10      PV20        RC
    04/05                2245.     428.      144.      641.      404.     1662.
    05/06                1220.      56.       40.      242.      231.     2809.

   SEASON       TMT      RP10      RP20      RV10      RV20
    04/05                 750.      720.     1313.     1069.
    05/06                1090.      961.      608.     1126.


*** Standard errors of means ***

Table                SEASON         TMT      SEASON
                                                TMT
rep.                     20           4           2
d.f.                      *          18           *
e.s.e.                    *       198.8           *
Except when comparing means with the same level(s) of
 SEASON                                       281.2

*** Least significant differences of means (5% level) ***

Table                SEASON         TMT      SEASON
                                                TMT
rep.                     20           4           2
d.f.                      *          18           *
l.s.d.                    *       590.7           *
Except when comparing means with the same level(s) of
 SEASON                                       835.4


***** Stratum standard errors and coefficients of variation *****

Variate: Nonsown

Stratum                   d.f.          s.e.         cv%

YEAR                         0             *           *
YEAR.REP                     2          90.8        10.2
YEAR.REP.PLOT               18         397.6        44.8


 ========== Summary of original data ==========


        TMT          PC
             Nobservd         Mean    Variance
      SEASON
       04/05            2       2245.0      638450
       05/06            2       1220.5      104424

      Margin            4       1732.8      597492


        TMT        PP10
```

	Nobservd	Mean	Variance
SEASON			
04/05	2	428.5	122512
05/06	2	56.5	5100
Margin	4	242.5	88666

TMT	PP20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	144.5	11704
05/06	2	39.5	220
Margin	4	92.0	7650

TMT	PV10		
	Nobservd	Mean	Variance
SEASON			
04/05	2	641.5	5724
05/06	2	241.5	12324
Margin	4	441.5	59350

TMT	PV20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	404.0	20000
05/06	2	231.0	2178
Margin	4	317.5	17369

TMT	RC		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1661.5	65884
05/06	2	2809.0	354482
Margin	4	2235.2	579041

TMT	RP10		
	Nobservd	Mean	Variance
SEASON			
04/05	2	750.5	2244
05/06	2	1089.5	1256112
Margin	4	920.0	457759

TMT	RP20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	720.5	144
05/06	2	961.0	163592
Margin	4	840.8	73859

TMT	RV10 Nobservd	Mean	Variance
SEASON			
04/05	2	1313.0	12482
05/06	2	608.5	18624
Margin	4	960.8	175809

TMT	RV20 Nobservd	Mean	Variance
SEASON			
04/05	2	1069.0	2450
05/06	2	1126.0	212552
Margin	4	1097.5	72750

TMT	Margin Nobservd	Mean	Variance
SEASON			
04/05	20	937.8	439479
05/06	20	838.3	766585
Margin	40	888.0	590108

SEASON	REP	TMT	Nonsown	FITTED	RESIDUAL
04/05	1	PC	1680.0	2156.5	-476.5
04/05	2	PC	2810.0	2333.5	476.5
04/05	1	PP10	676.0	340.0	336.0
04/05	2	PP10	181.0	517.0	-336.0
04/05	1	PP20	68.0	56.0	12.0
04/05	2	PP20	221.0	233.0	-12.0
04/05	1	PV10	588.0	553.0	35.0
04/05	2	PV10	695.0	730.0	-35.0
04/05	1	PV20	304.0	315.5	-11.5
04/05	2	PV20	504.0	492.5	11.5
04/05	1	RC	1480.0	1573.0	-93.0
04/05	2	RC	1843.0	1750.0	93.0
04/05	1	RP10	717.0	662.0	55.0
04/05	2	RP10	784.0	839.0	-55.0
04/05	1	RP20	712.0	632.0	80.0
04/05	2	RP20	729.0	809.0	-80.0
04/05	1	RV10	1234.0	1224.5	9.5
04/05	2	RV10	1392.0	1401.5	-9.5
04/05	1	RV20	1034.0	980.5	53.5
04/05	2	RV20	1104.0	1157.5	-53.5
05/06	1	PC	1449.0	1200.0	249.0
05/06	2	PC	992.0	1241.0	-249.0
05/06	1	PP10	107.0	36.0	71.0
05/06	2	PP10	6.0	77.0	-71.0
05/06	1	PP20	29.0	19.0	10.0
05/06	2	PP20	50.0	60.0	-10.0
05/06	1	PV10	163.0	221.0	-58.0
05/06	2	PV10	320.0	262.0	58.0
05/06	1	PV20	264.0	210.5	53.5
05/06	2	PV20	198.0	251.5	-53.5
05/06	1	RC	3230.0	2788.5	441.5
05/06	2	RC	2388.0	2829.5	-441.5

05/06	1	RP10	297.0	1069.0	-772.0
05/06	2	RP10	1882.0	1110.0	772.0
05/06	1	RP20	675.0	940.5	-265.5
05/06	2	RP20	1247.0	981.5	265.5
05/06	1	RV10	512.0	588.0	-76.0
05/06	2	RV10	705.0	629.0	76.0
05/06	1	RV20	1452.0	1105.5	346.5
05/06	2	RV20	800.0	1146.5	-346.5

=============== Two seasons combined =================

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***** Analysis of variance *****

Variate: Total

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
YEAR stratum					
SEASON	1	595360.	595360.		
YEAR.REP stratum	2	46212.	23106.	0.15	
YEAR.REP.PLOT stratum					
TMT	9	8970929.	996770.	6.54	<.001
SEASON.TMT	9	3894112.	432679.	2.84	0.029
Residual	18	2744642.	152480.		
Total	39	16251256.			

***** Tables of means *****

Variate: Total

Grand mean 1190.

SEASON	04/05	05/06
	1312.	1068.

TMT	PC	PP10	PP20	PV10	PV20	RC	RP10
	1800.	754.	655.	845.	805.	2240.	1166.

TMT	RP20	RV10	RV20
	1137.	1163.	1333.

SEASON	TMT	PC	PP10	PP20	PV10	PV20	RC
04/05		2344.	1132.	828.	1166.	1006.	1662.
05/06		1255.	376.	482.	523.	604.	2818.

SEASON	TMT	RP10	RP20	RV10	RV20
04/05		1024.	1069.	1550.	1336.
05/06		1309.	1205.	776.	1330.

*** Standard errors of means ***

```
Table                SEASON         TMT      SEASON
                                                TMT
rep.                     20           4           2
d.f.                      *          18           *
e.s.e.                    *       195.2           *
Except when comparing means with the same level(s) of
 SEASON                                       276.1

*** Least significant differences of means (5% level) ***

Table                SEASON         TMT      SEASON
                                                TMT
rep.                     20           4           2
d.f.                      *          18           *
l.s.d.                    *       580.1           *
Except when comparing means with the same level(s) of
 SEASON                                       820.4


***** Stratum standard errors and coefficients of variation *****

Variate: Total

Stratum                   d.f.          s.e.         cv%

YEAR                         0             *           *
YEAR.REP                     2          48.1         4.0
YEAR.REP.PLOT               18         390.5        32.8


 ========== Summary of original data ==========


         TMT          PC
             Nobservd         Mean    Variance
      SEASON
       04/05            2         2344      437112
       05/06            2         1255      133128

      Margin            4         1800      585750


         TMT        PP10
             Nobservd         Mean    Variance
      SEASON
       04/05            2         1132      229164
       05/06            2          376         338

      Margin            4          754      266761


         TMT        PP20
             Nobservd         Mean    Variance
      SEASON
       04/05            2          828        1682
       05/06            2          482        3784

      Margin            4          655       41612
```

TMT	PV10		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1166	65884
05/06	2	523	12168
Margin	4	845	164048

TMT	PV20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1006	3120
05/06	2	604	17672
Margin	4	805	60665

TMT	RC		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1662	65522
05/06	2	2818	339488
Margin	4	2240	580449

TMT	RP10		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1024	420
05/06	2	1309	1098162
Margin	4	1166	393364

TMT	RP20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1069	3042
05/06	2	1205	135200
Margin	4	1137	52246

TMT	RV10		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1550	7812
05/06	2	776	8580
Margin	4	1163	205673

TMT	RV20		
	Nobservd	Mean	Variance
SEASON			
04/05	2	1336	760
05/06	2	1330	227812

Margin	4	1333	76207

TMT	Margin Nobservd	Mean	Variance
SEASON			
04/05	20	1312	229214
05/06	20	1068	594781
Margin	40	1190	416699

SEASON	REP	TMT	Total	FITTED	RESIDUAL
04/05	1	PC	1877	2296	-419.5
04/05	2	PC	2812	2393	419.5
04/05	1	PP10	1470	1083	386.5
04/05	2	PP10	793	1180	-386.5
04/05	1	PP20	857	780	77.0
04/05	2	PP20	799	876	-77.0
04/05	1	PV10	985	1118	-133.4
04/05	2	PV10	1348	1215	133.4
04/05	1	PV20	1045	957	87.6
04/05	2	PV20	966	1054	-87.6
04/05	1	RC	1481	1614	-133.0
04/05	2	RC	1843	1710	133.0
04/05	1	RP10	1009	975	33.6
04/05	2	RP10	1038	1072	-33.6
04/05	1	RP20	1108	1021	87.1
04/05	2	RP20	1030	1117	-87.1
04/05	1	RV10	1488	1502	-14.4
04/05	2	RV10	1613	1599	14.4
04/05	1	RV20	1317	1288	28.5
04/05	2	RV20	1356	1385	-28.6
05/06	1	PC	1513	1256	256.6
05/06	2	PC	997	1254	-256.6
05/06	1	PP10	389	377	11.6
05/06	2	PP10	363	375	-11.6
05/06	1	PP20	526	484	42.1
05/06	2	PP20	439	481	-42.1
05/06	1	PV10	445	524	-79.4
05/06	2	PV10	601	522	79.4
05/06	1	PV20	698	605	92.6
05/06	2	PV20	510	603	-92.6
05/06	1	RC	3230	2819	410.7
05/06	2	RC	2406	2817	-410.7
05/06	1	RP10	568	1310	-742.4
05/06	2	RP10	2050	1308	742.4
05/06	1	RP20	945	1206	-261.4
05/06	2	RP20	1465	1204	261.4
05/06	1	RV10	710	777	-66.9
05/06	2	RV10	841	774	66.8
05/06	1	RV20	1667	1331	336.1
05/06	2	RV20	992	1328	-336.1

Appendix B

MECHANISATION COST

GENERAL INPUTS:	Feb-04
Inflation Rate	6%
Interest rate (risk free)	13%
Risk premium	0%
Repair and maintenance as % of orig. cost	9%
Insurance and housing as % of Value	5%
Specific Fuel Consumption [/kW.h]	0.34
Fuel Price [R per /]	R5.00
Lubrication % of Fuel Cost	15%
Annual wage for tractor driver	R23,520.00
Annual wage for assistant	R10,000.00
Total Farm Area [ha]	

	RIP	PLOUGH	DISC	SEED COVER
Operation Mechanisation Costs per ha (= Row 79)	R94.43	R175.37	R106.13	R41.92

MECHANISATION INPUT TABLE:	Power Source	Implement	Power Source	Implement	Power Source	Implement	Power Source	Implement
Machine Description	Tractor	Ripper	Tractor	Plough 3Furrow	Tractor	Disc	Tractor	Roler
Tractor 2WD / 4WD; Implement Width / Capacity	2WD	4.7	2WD	1.5	2WD	1.6	2WD	5.6
kW Available / Required	75	60	75	40	75	28	75	25
New price	R125,000.00	R5,000.00	R125,000.00	R12,000.00	R125,000.00	R22,000.00	R125,000.00	
Planning period [h]	8000	3500	8000	5000	8000	5000	8000	5000
Used price (10% of "New price")	R50,000.00	R1,000.00	R50,000.00	R5,000.00	R50,000.00	R10,000.00	R50,000.00	
Annual repair and maintenance (% of orig. cost)	9%	6%	9%	6%	9%	6%	9%	9%
Average equipment use per year [h]	1000	300	1000	300	1000	300	1000	300
Area per operation [ha]	25	25	25	25	25	25	25	25
Speed of operation [km/h]	-------	4	-------	5.8	-------	9	-------	6
Efficiency of operation - N	-------	70%	-------	70%	-------	70%	-------	60%
Time allowed to complete operation [h]	300	300	300	300	300	300	300	300
Number of labourers per implement	1	0	1	0	1	0	1	0
Additional operation costs per ha (e.g. chemical / ha)	-------	R0.00	-------	R0.00	-------	R0.00	-------	R0.00

MECHANISATION COST CALCULATIONS:

Planning period (years)	*8*	*12*	*8*	*17*	*8*	*17*	*8*	*17*
Real discount rate (Inflation free)	*6.60%*	*6.60%*	*6.60%*	*6.60%*	*6.60%*	*6.60%*	*6.60%*	*6.60%*
Real discount factor: [1 / (1+i)^n]	*0.5995*	*0.4742*	*0.5995*	*0.3444*	*0.5995*	*0.3444*	*0.5995*	*0.3444*
Capital recovery factor: [i(1+i)^n / (1+i)^n-1]	*0.1649*	*0.1256*	*0.1649*	*0.1007*	*0.1649*	*0.1007*	*0.1649*	*0.1007*
Work Rate [ha/h]	*0.76*	*0.76*	*0.62*	*0.62*	*1.01*	*1.01*	*1.31*	*1.31*
Work Rate [h/ha]	*1.32*	*1.32*	*1.62*	*1.62*	*0.99*	*0.99*	*0.76*	*0.76*
Operation duration [h]	*33*	*33*	*41*	*41*	*25*	*25*	*19*	*19*
Number of units required	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Operation duration per unit [h]	*33*	*33*	*41*	*41*	*25*	*25*	*19*	*19*
Tractor load	*80%*	----------	*53%*	----------	*37%*	----------	*33%*	----------
Specific Fuel Consumption [l/kW.h]	*0.3228*	*20*	*0.3605*	*14*	*0.4504*	*10*	*0.4893*	*9*
Fuel Consumption [l/h]	*13.56*		*10.09*		*8.83*		*7.34*	
Energy [kW.h/ha]	***99***	***79***	***122***	***65***	***74***	***28***	***57***	***19***

Capital Recovery (per year)	R15,669.79	R568.44	R15,669.79	R1,035.34	R15,669.79	R1,869.21	R15,669.79	R0.00
Insurance and housing	R4,375.00	R150.00	R4,375.00	R425.00	R4,375.00	R800.00	R4,375.00	R0.00
Labour (Average equipment use / 1920 hours)	R12,250.00	R0.00	R12,250.00	R0.00	R12,250.00	R0.00	R12,250.00	R0.00
Total Annual Ownership Costs	R32,294.79	R718.44	R32,294.79	R1,460.34	R32,294.79	R2,669.21	R32,294.79	R0.00
Total Ownership cost per hour	R976.59	R21.73	R797.19	R36.05	R1,302.13	R107.62	R1,692.76	R0.00
Total Ownership cost per ha	R1,291.79	R28.74	R1,291.79	R58.41	R1,291.79	R106.77	R1,291.79	R0.00

Operation Ownership Costs

Capital Recovery per operation	R518.18	R62.66	R634.80	R139.81	R388.64	R154.53	R298.95	R0.00
Insurance and housing per operation	R144.68	R16.53	R177.23	R57.39	R108.51	R66.14	R83.47	R0.00
Labour per operation	R405.09	R0.00	R496.26	R0.00	R303.82	R0.00	R233.71	R0.00
Operation Ownership Costs per Operation	R1,067.95	R79.19	R1,308.29	R197.20	R800.96	R220.67	R616.12	R0.00
Operation Ownership Costs per hour	R32.29	R2.39	R32.29	R4.87	R32.29	R8.90	R32.29	R0.00
Operation Ownership Costs per ha	R42.72	R3.17	R52.33	R7.89	R32.04	R8.83	R24.64	R0.00
	R45.89		R60.22		R40.87		R24.64	

Operation Operating Costs

Fuel Cost	R2,241.51	----------	R2,044.44	----------	R1,094.77	----------	R700.07	----------
Lubrication	R336.23	----------	R306.67	----------	R164.22	----------	R105.01	----------
Repairs and Maintenance	R351.36	R33.07	R430.43	R97.23	R263.52	R109.13	R202.71	R0.00
Addisional operation costs	----------	R0.00	----------	R0.00	----------	R0.00	----------	R0.00
Total Annual Operating Costs	R2,929.09	R33.07	R2,781.53	R97.23	R1,522.50	R109.13	R1,007.79	R0.00
Total Operating cost per hour	R88.58	R1.00	R68.66	R2.40	R61.39	R4.40	R52.82	R0.00
Total Operating Costs per ha	R117.16	R1.32	R111.26	R3.89	R60.90	R4.37	R40.31	R0.00
	R118.49		R115.15		R65.27		R40.31	

Total Operation Mechanisation Cost

Total Operation Mechanisation Costs	R3,997.04	R112.26	R4,089.82	R294.42	R2,323.46	R329.80	R1,623.91	R0.00
Total Operation Mechanisation Costs per hour	R120.87	R3.39	R100.96	R7.27	R93.68	R13.30	R85.12	R0.00
Total Operation Mechanisation Costs per cumulative ha	R159.88	R4.49	R163.59	R11.78	R92.94	R13.19	R64.96	R0.00
Sum Cumulative Operation Mechanisation Costs per ha	R94.43		R175.37		R106.13		R41.92	